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PULSED NUCLEAR RADIATION INDUCED TRANSIENTS IN ELECTRONIC PARTS AND MATERIALS
(Godiva IV & V)

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PULSED NUCLEAR RADIATION INDUCED TRANSIENTS IN ELECTRONIC PARTS AND MATERIALS (GODIVA IV & V)

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Abstract

Pulsed nuclear radiation induced changes in the electrical characteristics of electronic parts and materials obtained in two experiments at the Godiva II Reactor (Los Alamos) are described and discussed. The electronic parts investigated and monitored during exposure include coaxial cables, resistors, capacitors, rectifiers, and magnetic cores of various types, values, and materials. Most of the parts during exposure show transient parameter changes which exceed the tolerance values and then generally recover to their nominal values some time after completion of the radiation pulse. Some of the data show inconsistencies which prevent the authors from drawing definite and quantitative conclusions at the present time. In some cases, e.g., low and high value resistors, NiCr thin-film resistors of various values, and ceramic capacitors, the data show certain repetitive patterns in the behavior of these parts which seem to permit a limited qualitative prediction of the responses of these components under similar environmental conditions. Experiments at Godiva-type (pulsed) facilities are being continued.

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INTRODUCTION

This report is one of a continuing series describing the results of experiments conducted by USAELRDL on the effects of high-dose and dose-rate pulsed nuclear radiation on electronic parts and materials. The experimental program has the objective of acquiring data on the effects of this type of radiation on electronic parts and materials to establish the mechanism of the changes, or damage, and to provide data for improving their radiation tolerance by developing either inherent radiation stability or applying compensation techniques.

The experiments which are the subject of this report were conducted at the Godiva II Facility, Los Alamos, New Mexico, during August 1959 and June 1960. The report is a complete presentation of all the data obtained during these two experiments, referred to as Godiva IV & V. No detailed interpretation has been attempted because of certain inconsistencies which are apparent in the results.

EXPERIMENTAL PROCEDURE

Nuclear Radiation Facility

The radiation facility used in these experiments was the Godiva II Reactor located at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

This reactor is a bare critical uranium assembly enriched to approximately 90% in U-235; it is capable of delivering high-intensity pulses of neutron and gamma radiation. The average flux rate of leakage neutrons used for irradiation reaches 10^{17} n/cm^2-sec near the core surface with integrated fluxes of 10^{13} n/cm^2. The generated gamma fluxes yield doses and dose rates of the order of 10^3 rads and 10^7 rads/sec, respectively. The radiation pulse width at half-height is approximately 80 μsec.[1,2]

Description of Experimental Setup

1. *Instrumentation*

The parts and materials selected for these experiments were instrumented and exposed to nuclear radiation pulses from the Godiva reactor and their performance characteristics were monitored during exposure. The individual parts were soldered on BNC coaxial connectors, or directly to coaxial cables, and potted with paraffin to prevent air ionization. The parts were then placed at determined distances from the reactor core from which cables led to the parameter measuring circuits. These circuits were located at a distance from the reactor where the radiation level was known to be low enough to preclude any transient effects in the measuring and recording instrumentation. All cable connections in the vicinity of the reactor were packed with silicone grease as a precaution to prevent air ionization in the cable junctions. The measuring circuits, schematically shown on each graph, were designed to provide output voltage pulses which could be related by a suitable calibration to a change in the electrical parameter (R, I, L, C, etc.) of the part under exposure.

The transient voltage outputs of the measuring circuits were amplified when necessary for display on cathode-ray oscilloscopes, which were operated in the single sweep mode, and prior to the initiation of the radiation pulse triggered with signals provided by the reactor facility. The oscilloscope traces were recorded by photographic means (Polaroid camera).

Figure 1 shows schematically the instrumentation setup for the experiments conducted at the Godiva reactor; the setup incorporates the measuring or detecting circuitry, amplifiers, oscilloscopes, and cameras described above.

The parts tested were mounted on an exposure stand and connected through 30 ft of coaxial cable to the measuring instrumentation. The amplifier circuitry consisted of two separate sections to provide amplification and matching for the quarter-mile length of coaxial cable between the Kiva, in which the reactor was located, and the reactor control room, in which the recording instrumentation was assembled.

2. *Calibration*

The dc measuring or detecting circuits used in the experiments are schematically shown in Fig. 2 a through c with the formulas from which the plotted values were computed.

The ac circuits used for measuring capacitance and inductance were calibrated prior to the experiments and are shown in Fig. 2 d and e. The calibration procedure for the capacitance circuit consisted of making measurements with the test circuit using a variable capacitor in place of the test sample C and noting the change in the LC circuit voltage as a function of change in capacitance (a typical calibration curve with E_c normalized is shown in Fig. 3 a. Thus, any change in the voltage swing of the LC circuit due to the irradiation of the capacitor C can be translated by means of the calibration curve into an equivalent capacitance change. The magnitude and duration of the transient effect are measured from the modulation envelope.

The test circuit for measuring changes in inductance is similar to that for the capacitance measurement described above. The change of inductance is measured as an amplitude modulation of the voltage E_L from which the magnitude and the duration of the transient changes are determined.

Calibration of the test circuit is accomplished using a variable air capacitor and noting the change in the LC circuit voltage as a function of capacitance C. The equivalent inductance is calculated as

$$L = \frac{L_o \cdot C}{C'}$$

where

L = inductance for a particular value of E_L

L_o = inductance of the core under test

C' = capacitance of the connecting cable and circuitry.

(Figure 3 b shows a typical calibration curve with normalized E_L). Thus, any change in the amplitude of E_L due to irradiation of the inductor may be translated by means of the calibration curve into an equivalent inductance change.

To avoid ambiguity in measuring capacitance or inductance, the LC product is chosen either less than or greater than but not equal to $1/(2\pi f)^2$. Thus, for LC $< 1/(2\pi f)^2$, an increase in C or L appears first as an increase in the LC voltage; for LC $> 1/(2\pi f)^2$, an increase in C or L causes a decrease in this voltage amplitude.

3. *Dosimetry*

Sulfur pellets were placed adjacent to the parts during exposure to determine the total fast neutron ($E > 2.5$ Mev) doses of each nuclear pulse (see Table I parts List). For dose-rate measurements, the output of a SEMIRAD (Secondary Electron-Mixed-Radiation Detector) was recorded for each burst.

In this report, dose and dose rate were used equivalently because of the assumed equal duration and height of the single radiation pulses.

PARTS TESTED

A large variety of passive electronic parts were exposed in the two Godiva experiments: Godiva IV during August 1959, and Godiva V during June 1960. Included were: Cables RG-62 and RG-63, both with a semisolid dielectric (polyethylene and air), various types of resistors ranging from 100 ohms to 1 megohm with different power ratings, micromodule thin-film resistors, capacitors of ceramic and tantalum types, silicon and selenium rectifiers, and magnetic ferrite cores. The parts were tested under varied conditions of applied voltage, circuitry, total dose or dose rate, repeated exposure, etc. A detailed listing of the parts is presented in Table I.

RESULTS AND DISCUSSION

Results of the dc leakage current and capacitance measurements on coaxial cables are shown in Fig. 4-9. For the leakage current measurements on RG-62 cable, the samples were mounted with their paraffin potted or unpotted ends directed towards the reactor; the measurement on the RG-63 cable was made on a sample with its center portion coiled in a one-turn, 6"-diameter loop placed at the reactor. The capacitance measurement was made on a loop of cable also; this sample consisted of an 80' length of cable with its center coiled in a two-turn, 6"-diameter loop placed at the reactor.

Cables, Coaxial

Figures 4 and 5 represent the transient leakage current (recorded Δv is converted to leakage current Δi) observed in a potted RG-62 cable sample, connected to the measuring circuit in which the measuring resistor was varied from shot to shot as indicated. Cables connected to low-impedance circuits (R_L = 10 or 100 ohms) showed leakage currents of the order of 10 ma swinging from one polarity to the other. The same sample measured with higher impedance circuits (R_L = 1 kohm to 1 megohm displayed decreasing swing and currents of the order of only 10 to 100 μa.

In Figure 6, the voltage dependence of peak current is shown for unpotted cables. The load resistor was kept constant at 10 kohm and the applied voltage varied in steps from +6 v to +90 v. Unidirectional deflections were observed with peak currents ranging from +30 to +300 μa; except in one case, with an applied voltage of +6 v, the peak current was $-200\,\mu$a.

A comparison of effects in potted and unpotted cables (Fig. 7) for which the applied voltage and the load resistor were kept constant at +45 v and 10 kohm, respectively, supports the assumption that when irradiated with identical doses, unpotted terminals show higher currents because of lower "shunt resistance" caused by air ionization (compare curve 2 with curve 4, Fig. 7). (The transient leakage currents–by whatever mechanism they are caused–can be accounted for by the insertion of transient "shunt resistance" calculated as in Fig. 2c). Dose or dose-rate dependency is also seen qualitatively (curves 1, 2, 5, 6, Fig. 7). Leakage currents range from 20 to 200 μa in both potted and unpotted cables. A curve for leakage current (70 μa) in RG-63 and an overall capacitance change (+15%) in RG-62 are shown in Fig. 8 and 9. In the capacitance measurement, the pronounced change of capacitance followed closely the shape of the burst, and recovery was complete within 1000 μsec.

As a very general conclusion, it may be said that transient effects in cables indicate dependence upon dose rate (or dose), applied voltage and polarity, impedance of measuring circuit, potting, and perhaps other parameters. One of such parameters which may play a significant role in the shape, magnitude, and duration of the transient effect is repeated exposure. Because of the multitude of the parameters whose introduction is not yet understood and the very limited number of data obtained to date, no quantitative relationships can be derived, let alone any interpretation of the physical mechanisms involved.

Component Parts

The conversion of the oscilloscope recorded voltage changes Δv to the plotted component characteristics was obtained by using the appropriate formula given in Fig. 2. It is realized that this evaluation procedure ignores completely the fact that the observed Δv is a result of the superposition of the transient leakage current (or shunt resistance occurring simultaneously in the cable connecting the part to the measuring circuit) and the transient effect in the component proper. However, this procedure has been followed because in the absence of any quantitative and reproducible determination of the cable behavior, the transient cable effect cannot be subtracted. Therefore, at present, the component, plus the cable connecting it to the measuring instrumentation, must be considered as one entity until the effect in the component and the one in the connecting medium can be separated.

The following evaluation of the results is presented in the light of the foregoing explanation.

1. *Resistors*

a. *Standard Type*

Resistors of wire wound, carbon film, metal film carbon composition, and tin oxide film types were tested. Their resistance ranged from 100 ohm to 1 megohm. The data for these resistors are grouped according to the nominal resistor value rather than the composition. It must be noted that the 100-ohm resistors were measured in the so-called "forward voltage drop" (fvd) circuit (normally used for the measurement of the fvd in rectifiers, see below) with only 3 v to 6 v applied in order to keep the current drain low; whereas, all other resistors were measured with bridge circuits with 22.5 v to 45 v applied. In all cases, RG-62 cable was used to connect the part to the measuring circuitry.

The 100-ohm resistors showed transient resistance increases of the order of 20% (Fig. 10-12).

In 1-kohm and 10-kohm resistors (Fig. 13-20) resistance changes ranging from −5% to +5% were observed.

100-, 237-, and 348-kohm resistors (Fig. 21-24) measured in equal-arm bridges had transient relative resistance changes unidirectional and/or bidirectional) from about −30% to +10%.

The 1-megohm resistors wired in parallel to represent a 100-kohm resistor and measured in a 100-kohm equal-arm bridge showed a transient increase in R of 5% consistently in three successive exposures (Fig. 25). Figure 26 presents data on 1-megohm resistors obtained with the nonequal arm bridge (to reduce output impedance to amplifier) as indicated on the graph. The major effect is a 20% to 60% decrease with subsequent "overshoot" (up to 10%) and apparently slower recovery (> 2 msec) than all other resistors which recovered within 1-2 msec to their initial value.

b. *Micromodule Resistors*

Figure 27 shows the results obtained on NiCr thin-film resistors that were prepared by vacum deposition on micromodule alumina wafers at USAELRDL. The bridges were approximately equal-arm and exact balance was achieved shortly before the irradiation burst by adjusting the potentiometer, as indicated in the drawing, for balance. Under irradiation, these resistors showed a consistent behavior regardless of their nominal value, namely, for all of them, the resistance increased between 10% and 20% followed by a complete recovery within 1 msec.

c. *Sensistors*

The only type tested, a 100-ohm sensistor, showed the same behavior as a normal resistor of the same value (Fig. 10).

No permanent damage could be noted for any resistor.

2. *Capacitors*

Leakage current measurements were made on low-value (0.003 μf, 0.01 μf) ceramic and high-value (33 μf, 60 μf) tantalum capacitors; the latter were of the foil, slug, and solid types.

The ceramic capacitors showed an inverse or "negative" leakage current, which seems to depend on the value of the irradiated part and the total dose or dose rate (Fig. 28). Figure 35 shows capacitance change as measured in the two ceramic capacitor types.

The tantalum capacitors (Fig. 29-34) displayed a somewhat inconsistent behavior. While the majority of the capacitor types also exhibited a negative leakage current, some of them showed only true leakage (positive plotted current). In general, the magnitude of the effects varied from type to type. It is not yet possible to correlate these phenomena either with the value or with the composition of the capacitor. One of the reasons for the erratic behavior may be that not all of the capacitors were formed at the appropriate working voltage prior to exposure, but this could not be determined positively. Contrary to the immediate recovery observed in all other components studied so far, recovery in the tantalum capacitors can take from 50 msec to a few seconds, with the lingering part of the transient in its "plateaulike" shape resembling very closely the trailing edge of the fission pulse itself (Fig. 31).[5]

3. *Rectifiers, Silicon and Selenium (Fig. 36 and 37)*

The transient changes in forward voltage drop ($R_f \sim 1 - 2$ kohm) and reverse current in some Silicon and Selenium rectifiers were examined under pulsed nuclear radiation. While the forward voltage drop in the unpotted Silicon diodes showed high increases (30%), the

Silicon and Selenium diodes, if potted, showed only a small increase with a subsequent decrease. Recovery was complete within about 10 msec.[6]

The reverse current (about 100 μa) observed in the Silicon diodes was much higher than in the Selenium diodes (25 μa), and in both cases lasted no longer than 1-2 msec (Fig. 38 and 39).

4. *Magnetic Cores, Ferrite*

The inductance of a number of wound cores of MnZn and NiZn ferrite materials was monitored during irradiation. Using the circuits shown on the graph (Fig. 40), changes in the inductance (−25% to +15%) were observed. There appears to be no obvious connections between composition and radiation sensitivity; however, the cores with the lowest initial permeability were found to undergo the smallest change. Unlike the transients observed for other passive parts, the time required for recovery of the inductance transients is essentially the duration of the radiation pulse (prompt critical spike).

CONCLUSIONS

This report represents a complete summary of the data obtained on components exposed in two experiments at the Los Alamos Scientific Laboratory Godiva II pulsed reactor.

The most pronounced and, at present, unpredictable effects are seen in cables and, when used as an interconnecting or transmission medium, will obviously influence the observations of component effects. An extensive program of cable effect studies considering the many possible contributing parameters has been devised. Future experiments should shed more light on the causes of the transient cable behavior. There are too many unknown variables, or as yet unmeasured parameters, and certain instrumentation and measuring difficulties to permit any quantitative or definite conclusion as regards the nature and mechanism of the true component effect at the present time.

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TABLE I

Legend for Part List and Graphs:

TND	Total neutron dose (neutrons /cm^2)
c.f.	carbon film
m.f.	metal film
c.c.	carbon composition
t.o.	tin oxide
w.w.	wire wound
th. f.	thin film
PE	polyethylene

Whenever blanks appear on part list or graphs the data were not available.

Asterisks on the graphs mark repeated exposures (compare part list).

Leakage current has been arbitrarily designated as positive for a positive Δv.

TABLE I (Continued)

Fig #	Curve #	Godiva #	Part Description	Type or Value	Material	Applied Voltage	Shot #	TND x 10^{12} E > 4 kev	Remarks
4	1	V	Cable	RG - 62	PE & Air	45 V	1	7.1	blank, potted
	2		"	"	"	45 V	2	5.9	blank, potted
	3		"	"	"	45 V	3	9.5	blank, potted
	4		"	"	"	45 V	8	6.0	blank, potted
5	1	V	"	"	"	45 V	5	6.9	blank, potted
	2		"	"	"	45 V	6	8.7	blank, potted
	3		"	"	"	45 V	7	8.1	blank, potted
	4		"	"	"	45 V	4	10.6	blank, potted
6	1	V	"	"	"	6 V	4	10.6	blank, unpotted
	2		"	"	"	12 V	5	6.9	blank, unpotted
	3		"	"	"	22.5 V	6	8.7	blank, unpotted
	4		"	"	"	45 V	7	8.1	blank, unpotted
	5		"	"	"	45 V	3	9.5	blank, potted
	6		"	"	"	90 V	8	6.0	blank, unpotted
7	1	IV	"	"	"	45 V	2	1.2	blank, potted
	2		"	"	"	45 V	1	5.0	blank, potted
	3		"	"	"	45 V	2	1.2	blank, unpotted
	4		"	"	"	45 V	1	5.0	blank, unpotted
	5		"	"	"	45 V	5	6.9	blank, potted
	6		"	"	"	45 V	7	8.1	blank, unpotted
	7'		"	"	"	45 V	3	9.5	Amplifiers probably failed
8	1	V	"	RG - 63	"	45 V	2	5.9	loop, potted
9	1	V	"	RG - 62	"	670 kc	1	7.1	
10	1	IV	Sensistor	100 Ω, 1/8W	doped single	6 V	1	5.0	
	2		"	100 Ω, 1/8W	crystal,	6 V	2	1.2	
	3		"	100 Ω, 1/8W	silicon	6 V	6	8.3	

TABLE I (Continued)

Fig #	Curve #	Godiva #	Part Description	Type or Value	Material	Applied Voltage	Shot #	TND x 10^{12} E > 4 kev	Remarks
11	1	V	Resistor	100 Ω, 1/8W	c.f.	6 V	6	8.7	
	2		"	100 Ω, 1/4W	m.f.	12 V	2	5.9	2. exp. shot # 1
	3		"	100 Ω, 1 W	m.f.	6 V	7	8.1	
	4		"	100 Ω, 1/4W	m.f.	12 V	1	7.1	
	5		"	100 Ω, 1 W	c.f.	6 V	6	8.7	
12	1	V	"	100 Ω, 10 W	w.w.	6 V	4	10.6	
	2		"	100 Ω, 10 W	w.w.	6 V	7	8.1	
13	1	V	"	1 kΩ, 1/10 W	c.c.	45 V	5	6.9	on cable
	2		"	1 kΩ, 1/2 W	c.f.	45 V	1	7.1	
	3		"	1.1 kΩ, 1/8W		45 V	8	6.0	
	4		"	1 kΩ, 1/2 W	c.f.	45 V	2	5.9	2. exp. shot # 1
	5		"	1 kΩ, 1/10 W	c.c.	45 V	4	10.6	
	6		"	1 kΩ, 1/2 W	c.f.	45 V	5	6.9	on cable
	7		"	1 kΩ, 1/10 W	m.f.	45 V	6	8.7	
14	1	V	"	1 kΩ, 10 W	w.w.	45 V	3	9.5	
	2		"	1 kΩ, 1/2 W	m.f.	45 V	3	9.5	
	3		"	1.2kΩ, 1 W	c.c.	45 V	4	10.6	
	4		"	1 kΩ, 1/2 W	m.f.	45 V	6	8.7	
	5		"	1.2kΩ, 1 W	c.f.	45 V	1	7.1	
	6		"	1.2kΩ, 1 W	c.f.	45 V	2	5.9	2. exp. shot # 1
15	1	IV	"	1 kΩ	t.o.	45 V	5	6.7	
	2		"	1 kΩ	t.o.	45 V	5	6.7	
	3		"	1 kΩ	t.o.	45 V	8	11.6	
	4		"	1 kΩ	t.o.	45 V	7	10.1	
16	1	IV	"	1 kΩ	m.f.	45 V	5	6.7	
	2		"	1 kΩ	c.f.	45 V	4	6.2	
	3		"	1 kΩ	c.f.	45 V	3	-	
	4		"	1 kΩ	c.c.	45 V	6	8.3	

TABLE I (Continued)

Fig #	Curve #	Godiva #	Part Description	Type or Value	Material	Applied Voltage	Shot #	TND x 10^{12} E > 4 kev	Remarks
17	1	IV	Resistor	10 k Ω	m.f.	45 V	5	6.7	
	2		"	10 k Ω	m.f.	45 V	5	6.7	
	3		"	10 k Ω	m.f.	45 V	8	11.6	
	4		"	10 k Ω	m.f.	45 V	9	11.5	
	5		"	10 k Ω	m.f.	45 V	7	10.1	
18	1	IV	"	10 k Ω	m.f.	45 V	6	8.3	2. exp. shot # 5
	2		"	10 k Ω	c.c.	45 V	6	8.3	2. exp. shot # 5
	3		"	10 k Ω	m.f.	45 V	5	6.7	2. exp. shot # 4
	4		"	10 k Ω	c.c.	45 V	6	8.3	
19	1	IV	"	10 k Ω	c.f.	45 V	1	5.0	
	2		"	10 k Ω	c.f.	45 V	9	11.5	
	3		"	10 k Ω	c.f.	45 V	7	10.1	
	4		"	10 k Ω	c.f.	45 V	2	1.2	
	5		"	10 k Ω	c.f.	45 V	8	11.6	
	6		"	10 k Ω	c.c.	45 V	6	8.3	
20	1	V	"	10 kΩ,1/2W	c.f.	45 V	2	5.9	2. exp. shot # 1
	2		"	10 kΩ,1/2W	m.f.	45 V	8	6.0	
	3		"	10 kΩ,1/2W	m.f.	45 V	8	6.0	
	4		"	10 kΩ, 10W	v.w.	45 V	2	5.9	2. exp. shot # 1
	5		"	10 kΩ, 10W	v.w.	45 V	6	8.7	
	6		"	10 kΩ, 1 W	c.f.	45 V	2	5.9	2. exp. shot # 1
	7		"	12 kΩ, 1 W	c.c.	45 V	5	6.9	
21	1	V	"	75 kΩ,1/2W	m.f.	45 V	5	6.9	
	2		"	100 kΩ,1/2W	c.c.	45 V	4	10.6	
	3		"	100 kΩ,1/2W	t.o.	45 V	5	6.9	

TABLE I (Continued)

Fig #	Curve #	Godiva #	Part Description	Type or Value	Material	Applied Voltage	Shot #	TND x 10^{12} E > 4 kev	Remarks
22	1	IV	Resistor	100 k Ω	m.f.	45 V	6	8.3	
	2		"	100 k Ω	m.f.	45 V	5	6.7	
	3		"	100 k Ω	m.f.	45 V	9	11.5	
	4		"	100 k Ω	m.f.	45 V	8	11.6	
	5		"	100 k Ω	m.f.	45 V	7	10.1	
23	1	V	"	100 k Ω	-	45 V	3	-	
	2		"	100 k Ω	c.f.	45 V	5	6.7	
	3		"	100 k Ω	c.c.	45 V	6	8.3	
	4		"	100 k Ω	c.f.	45 V	4	6.2	
24	1	V	"	237 kΩ,1/2W	m.f.	22.5 V	7	8.1	
	2		"	237 kΩ, 1 W	m.f.	22.5 V	7	8.1	
	3		"	348 kΩ,1/4W	m.f.	45 V	3	9.5	
	4		"	348 kΩ,1/4W	m.f.	45 V	3	9.5	
25	1	IV	"	1 MΩ	m.f.	45 V	7	10.6	10 x 1 M in parallel
	2		"	1 MΩ	m.f.	45 V	8	11.6	" "
	3		"	1 MΩ	m.f.	45 V	9	11.5	" "
26	1	V	"	1 MΩ,1/2W	m.f.	45 V	3	9.5	
	2		"	1 MΩ, 1 W	c.c.	45 V	5	6.9	
	3		"	1 MΩ,1/10W	c.c.	45 V	5	6.9	2. exp.
	4		"	1 MΩ,1/2W	c.f.	45 V	4	10.6	
	5		"	1 MΩ	c.f.	45 V	4	6.2	

TABLE I (Continued)

Fig #	Curve #	Godiva #	Part Description	Type or Value	Material	Applied Voltage	Shot #	TMD x 10^{12} E > 4 kev	Remarks
27	1	V	mm - wafer 14	127 Ω	NiCr, th.f.	12 V	5	6.9	
	2		" " 11	135 Ω	" "	12 V	7	8.1	
	3		" " 11	135 Ω	" "	12 V	8	6.0	2. exp. shot # 7
	4		" " 12	373 Ω	" "	22.5 V	7	8.1	
	5		" " 12	373 Ω	" "	22.5 V	8	6.0	2. exp. shot # 7
	6		" " 13	11 k Ω	" "	22.5 V	7	8.1	
	7		" " 13	11 k Ω	" "	22.5 V	8	6.0	2. exp. shot # 7
28	1	IV	Capacitor	0.003 μf	ceramic	45 V	4	6.2	
	2		"	0.003 μf	ceramic	45 V	6	8.3	
	3		"	0.003 μf	ceramic	45 V	8	11.6	
	4		"	0.01 μf	ceramic	45 V	9	11.5	
29	1	IV	"	60 μf	Ta, foil	45 V	2	1.2	
	2		"	60 μf	Ta, foil	45 V	8	11.6	
	3		"	60 μf	Ta, foil	45 V	9	11.5	
	4		"	60 μf	Ta, foil	45 V	7	10.1	
30	1	IV	"	60 μf	Ta, foil	45 V	6	8.3	
	2		"	60 μf	Ta, foil	45 V	8	11.6	
	3		"	60 μf	Ta, foil	45 V	7	10.1	
31	1	IV	"	60 μf	Ta, foil	45 V	1	5.0	
32	1	IV	"	60 μf	Ta, slug	45 V	3	-	
	2		"	60 μf	Ta, slug	45 V	4	6.2	
33	1	IV	"	33 μf	Ta, solid	12 V	4	6.2	
	2		"	33 μf	Ta, solid	45 V	4	6.2	
	3		"	33 μf	Ta, solid	12 V	9	11.5	
	4		"	33 μf	Ta, solid	12 V	7	10.1	
	5		"	33 μf	Ta, solid	12 V	8	11.6	

TABLE I (Continued)

Fig #	Curve #	Godiva #	Part Description	Type or Value	Material	Applied Voltage	Shot #	TND x 10^{12} E > 4 kev	Remarks
34	1	IV	Capacitor	33 μf	Ta, solid	12 V	3	-	
	2		"	33 μf	Ta, solid	12 V	3	-	
	3		"	33 μf	Ta, solid	12 V	5	6.7	
	4		"	33 μf	Ta, solid	12 V	7	10.1	
	5		"	33 μf	Ta, solid	45 V	8	11.6	
35	1	IV	"	0.003 μf		160 kc	9	11.5	
	2		"	0.01 μf		230 kc	7	10.1	
	3		"	0.01 μf		150 kc	8	11.6	
36	1	IV	Rectifier	-	Si -Diode	90 V	4	6.2	cable end unpotted
	2		"	-	Si -Diode	90 V	3	-	cable end unpotted
	3		"	-	Si -Diode	90 V	4	6.2	cable end potted
	4		"	-	Si -Diode	90 V	3	-	cable end unpotted
37	1	IV	Rectifier	-	Se -Diode	90 V	1	5.0	
	2		"	-	Se -Diode	90 V	2	6.0	
38	1	IV	"	-	Se	45 V	5	6.7	on Fig # 26 also
	2		"	-	Se	45 V	7	10.1	
	3		"	-	Se	45 V	8	11.6	2. exp. shot # 7
	4		"	-	Se	45 V	9	11.5	3. exp. shot # 8
39	1	IV	"	-	Se	45 V	5	6.7	
	2		"	-	Si	45 V	6	8.3	
40	1	V	Core	H 3		120 kc	4	10.6	
	2		"	H 3		120 kc	5	6.9	
	3		"	H 3		170 kc	8	6.0	
	4		"	H 4		120 kc	6	8.7	
	5		"	T 2		120 kc	7	8.1	
	6		"	4373-2		170 kc	8	6.0	

INSTRUMENTATION SETUP
GODIVA

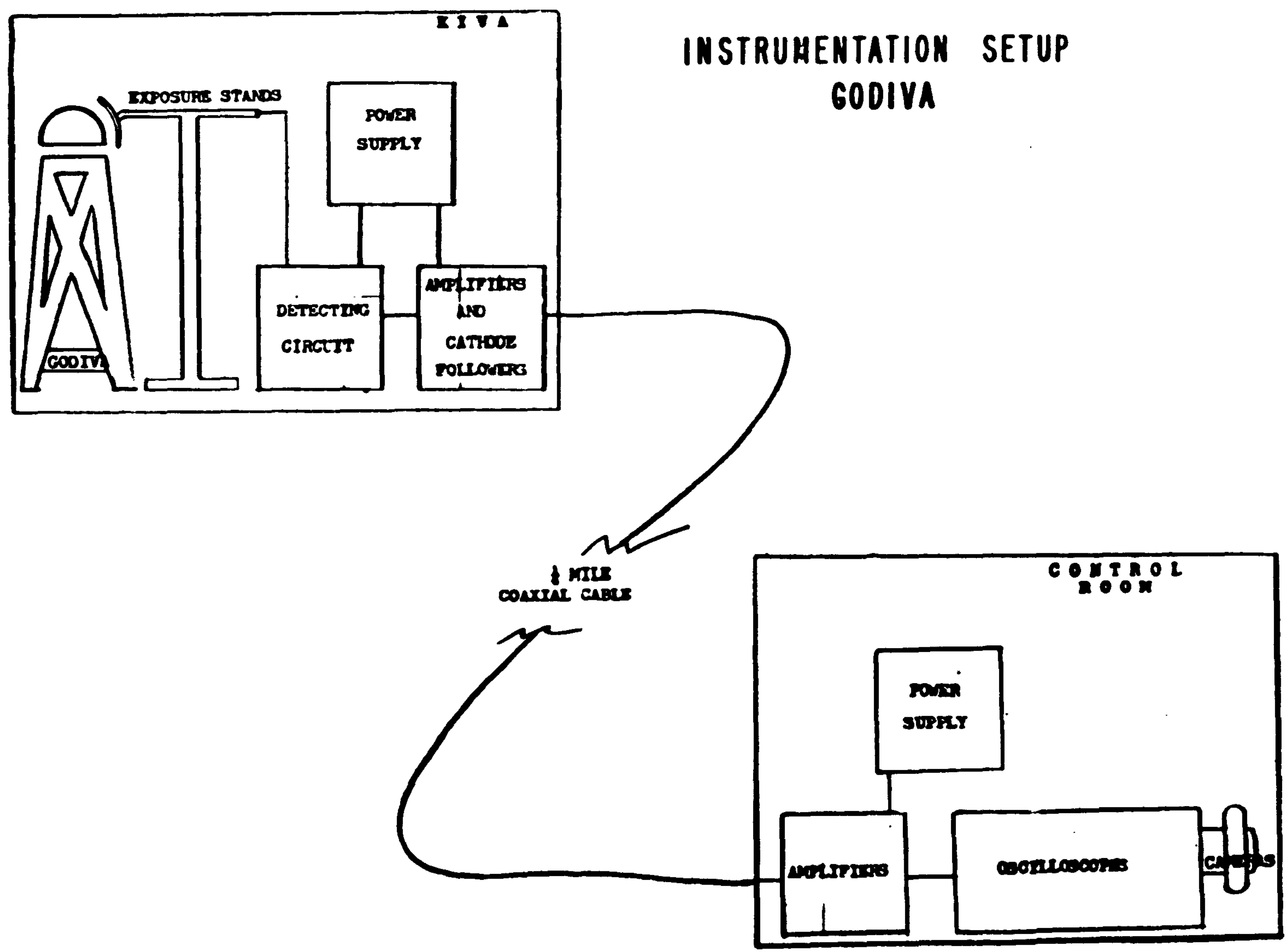
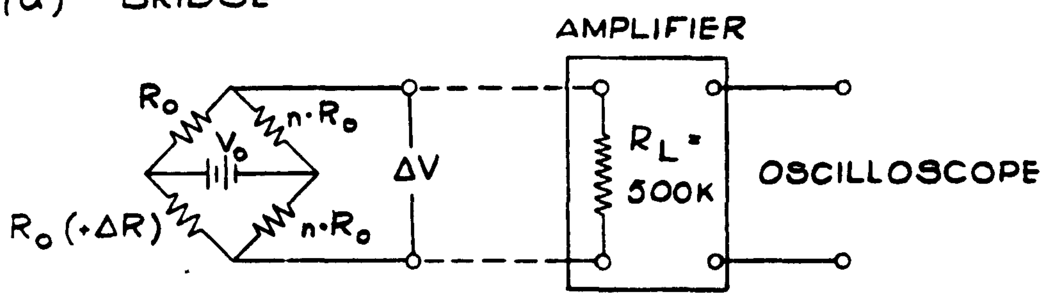


Fig. 1

FIGURE 2

DC MEASURING CIRCUITS

(a) BRIDGE



If $R_L \gg nR_o$, THEN THE BRIDGE OUTPUT ΔV IS (ALSO SEE REF. 3)

$$\frac{\Delta V}{V_o} = \left[\frac{n}{1+n} - \frac{n}{n+(1+\frac{\Delta R}{R_o})} \right] \qquad (1)$$

SETTING: $\frac{\Delta R}{R_o} = \rho$, $\frac{\Delta V}{V_o} = v$

(1) CAN BE WRITTEN
$$v = \frac{n}{1+n} \left[\frac{\rho}{(1+n)+\rho} \right] \qquad (2)$$

WHICH MAY BE EXPANDED IN SERIES FOR SMALL ρ: (5)

$$v = \rho \frac{n}{(1+n)^2} \left[1 - \frac{\rho}{1+n} + \ldots (-1)^{r-1} \left(\frac{\rho}{1+n}\right)^{r-1} \right] \qquad (3)$$

SINCE WE ARE INTERESTED IN FINDING ρ FROM AN OBSERVED v WE SOLVE (2) FOR ρ:

$$\rho = v \frac{(1+n)^2}{n - v(1+n)} \qquad (4)$$

WHICH AGAIN FOR SMALL (OBSERVED) v MAY BE EXPANDED IN A SERIES (5) IN ORDER TO OBTAIN FIRST (OR ANY ORDER) APPROXIMATIONS FOR ρ THAT ARE EASIER TO CALCULATE AND ESTIMATE THAN BY THE USE OF (4)

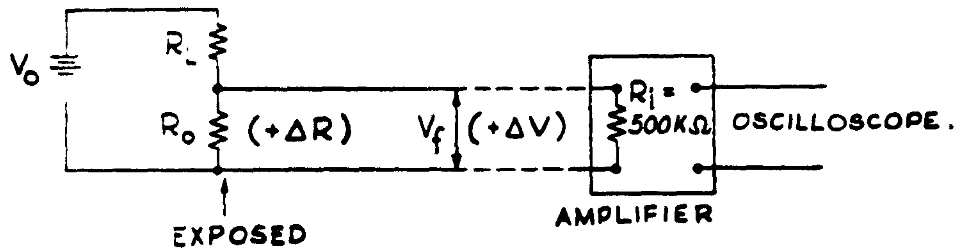
$$\rho = v \frac{(1+n)^2}{n} \left[1 + v \left(\frac{1+n}{n}\right) + \cdots\cdots \right]. \qquad (5)$$

FOR EQUAL ARM BRIDGE ($n=1$) ALL FORMULAS OF COURSE SIMPLIFY:

$$\rho = \frac{4}{\frac{1}{v} - 2} \quad (4a), \text{ etc.}$$

(FIG. 2 (CONT)

(b) FORWARD VOLTAGE DROP V_f



AGAIN ASSUMING $R_i \gg R_0$ THE RELATIVE CHANGE, $\frac{\Delta V}{V_0}$, OF THE fvd, V_f, DUE TO A CHANGE ΔR IN R_0 IS :

$$\frac{\Delta V}{V_0} = \frac{V_f + \Delta V}{V_0} - \frac{V_f}{V_0} = \frac{R_0 + \Delta R}{R_0 + \Delta R + R_L} - \frac{R_0}{R_0 + R_L} . \quad (1')$$

SUBSTITUTING $R_L = n R_0$; $\frac{\Delta V}{V_0} = v$; $\frac{\Delta R}{R_0} = \rho$

WE HAVE $$v = \left(\frac{1+\rho}{n+(1+\rho)} - \frac{1}{n+1}\right) = \left(\frac{n}{1+n} - \frac{n}{n+(1+\rho)}\right) = \frac{n}{1+n}\left[\frac{\rho}{(1+n)+\rho}\right] (2')$$

WHICH OF COURSE IS IDENTICAL TO THE BRIDGE WITH THE SAME EXPANSIONS AND SOLUTIONS FOR v AND ρ AS IN 2a. CONSEQUENTLY, IN FIRST APPROXIMATION, IE, $\Delta R \ll R_0$, WE HAVE IN BOTH CASES :

$$\rho = v \frac{(n+1)^2}{n}$$

WHICH FOR INSTANCE YIELDS :

$$\rho = \frac{\Delta V}{10}$$

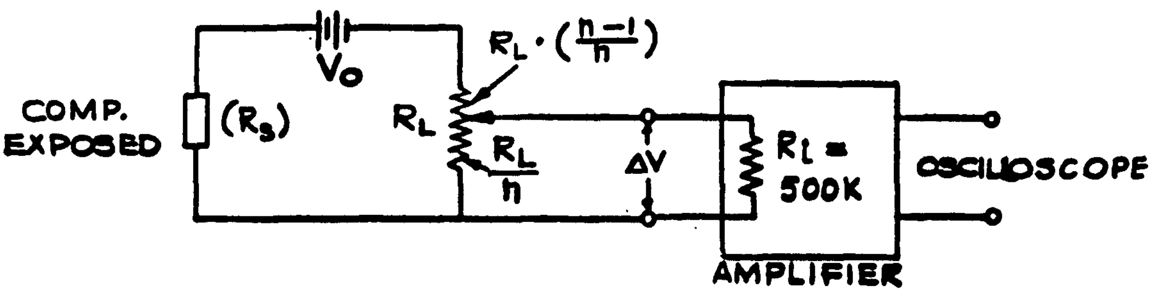
FOR $n = 1$ AND $V_0 = 40V$ (IN AN EQUAL ARM BRIDGE) ;

$$\rho = \frac{6}{5} \Delta V$$

FOR $n = 5$ AND $V_0 = 6V$ (IN A fvd CIRCUIT).

FIG. 2 (CONT)

(C) LEAKAGE OR REVERSE CURRENT



$n \geq 1$; (R_s) = TRANSIENT SHUNT RESISTANCE

$$\Delta i = \Delta V \cdot \frac{n}{R_L}$$

$$R_s = R_L \left(\frac{V_o}{\Delta V \cdot n} - 1 \right)$$

FOR $n = 1$ AND $\Delta V \ll V_o$ WE APPROXIMATE:

$$R_s \approx R_L \cdot \frac{V_o}{\Delta V}$$

FIGURE 2 (CONT.)
MEASURING CIRCUITS (AC)

(d) CAPACITANCE (e) INDUCTANCE

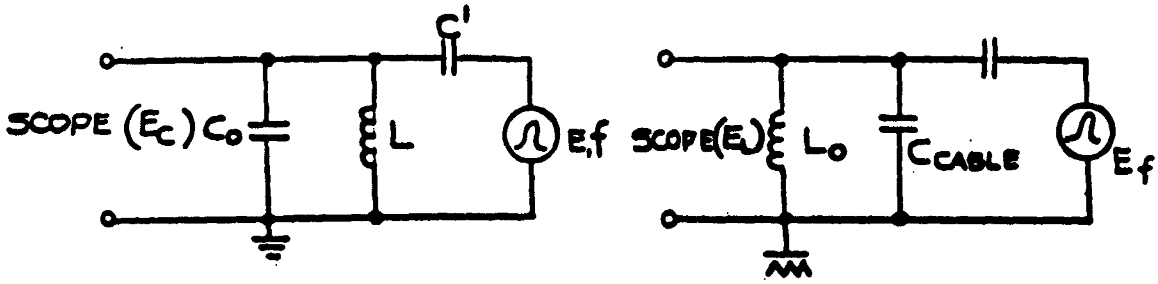
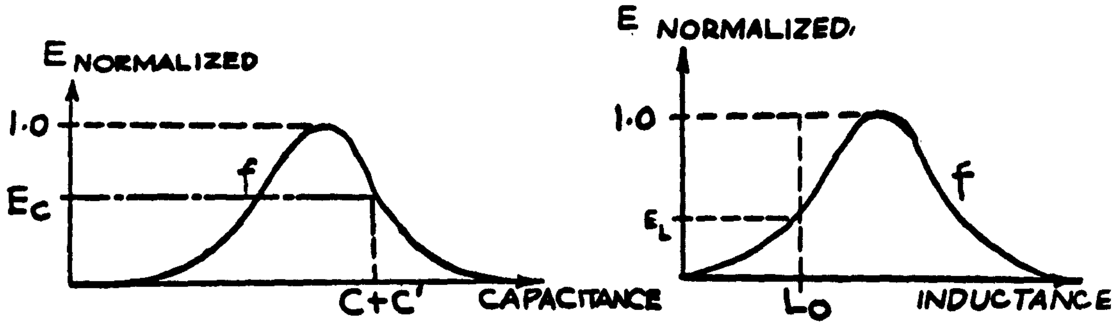


FIGURE 3



(a) (b)

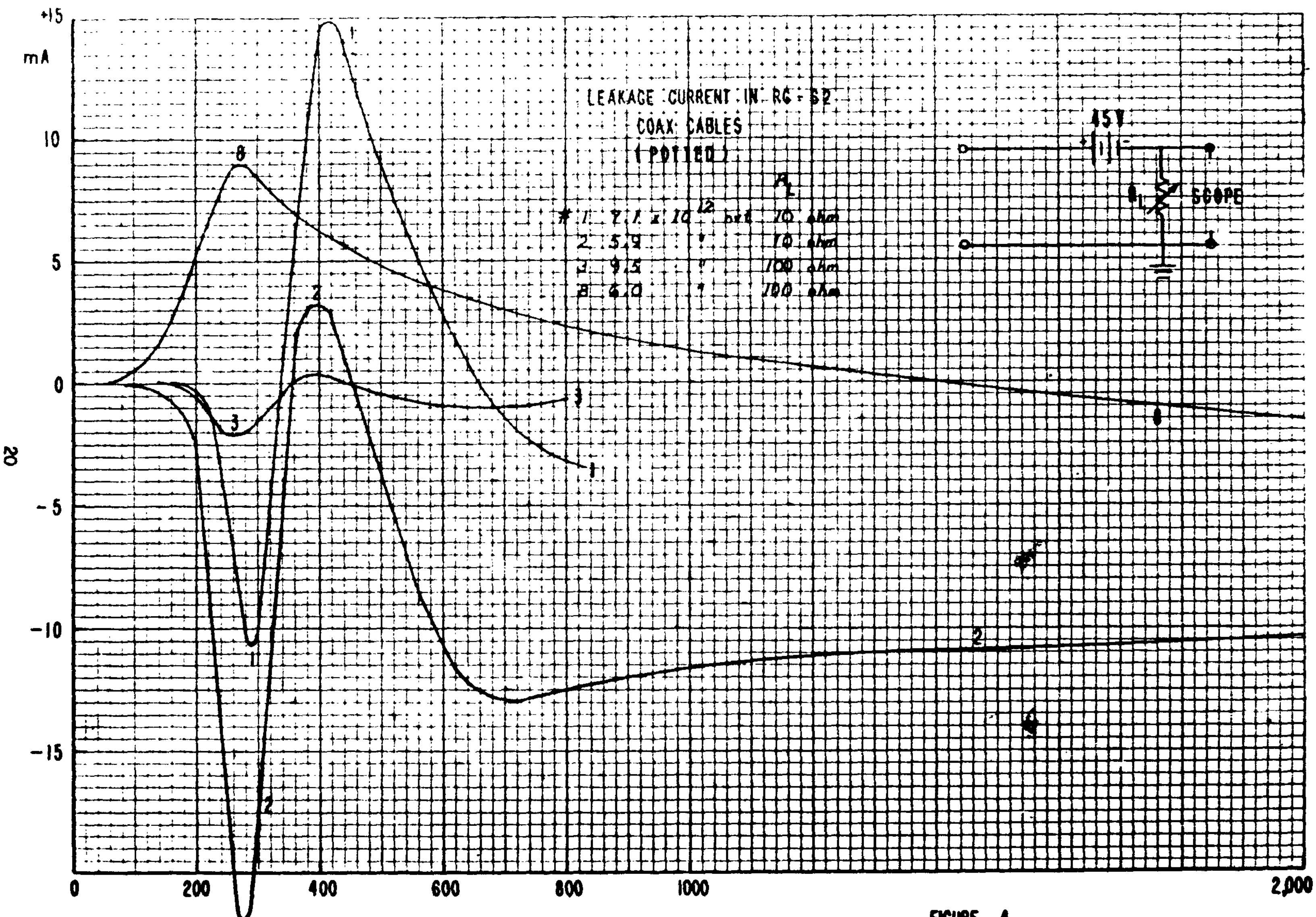
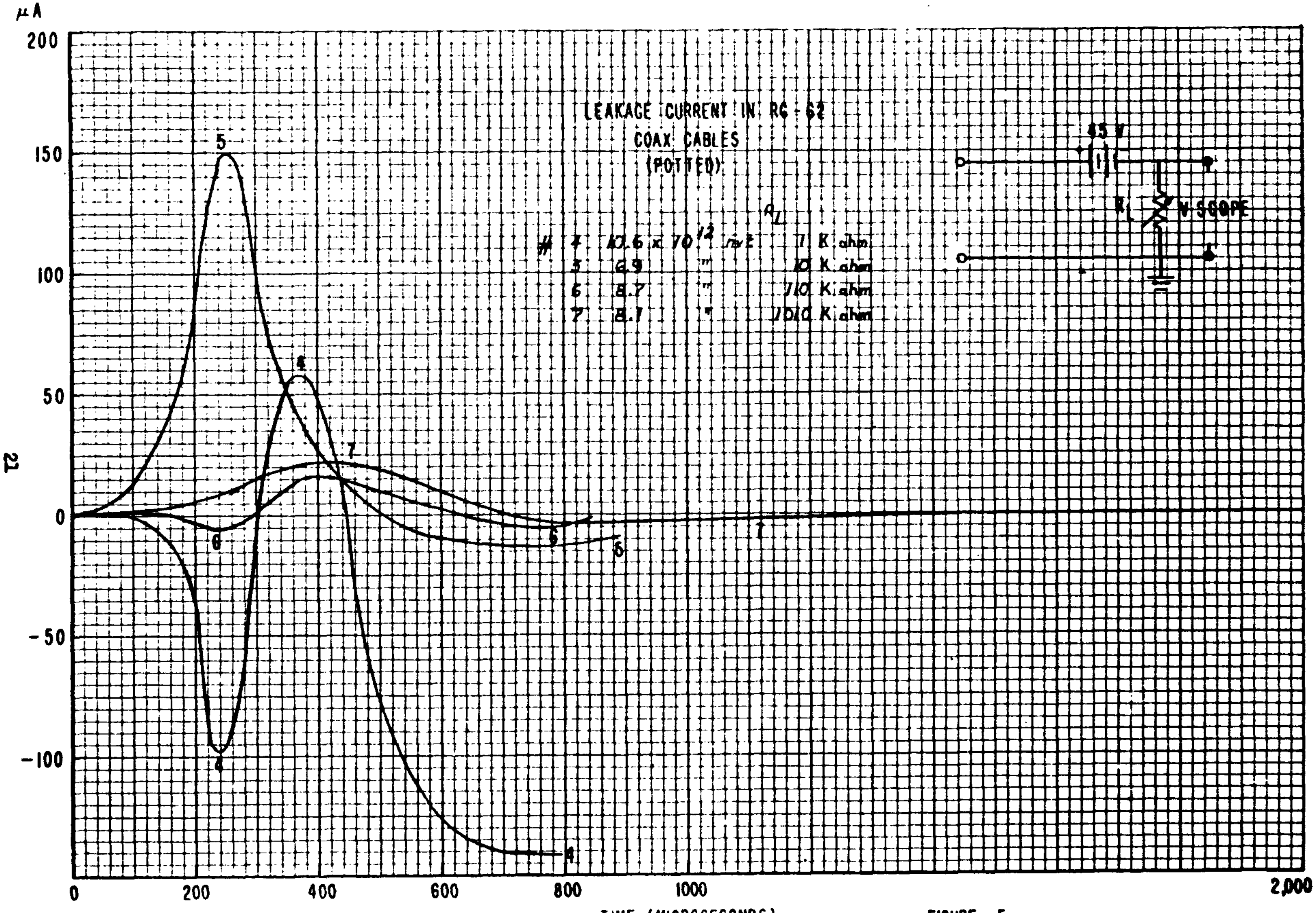

LEAKAGE CURRENT IN RG-62
COAX CABLES
(POTTED)
45 V
SCOPE
mA
+15
10
5
0
-5
-10
-15
0
200
400
600
800
1000
2,000
TIME (MICROSECONDS)

FIGURE 4



LEAKAGE CURRENT IN RG - 62
COAX CABLES
(POTTED)
R_L
4 10.6 x 10^12 1 K ohm
5 6.9 " 10 K ohm
6 8.7 " 110 K ohm
7 8.1 " 1010 K ohm
45 V
R_L
V SCOPE
μA
200
150
100
50
0
-50
-100
0
200
400
600
800
1000
2,000
TIME (MICROSECONDS)

FIGURE 5

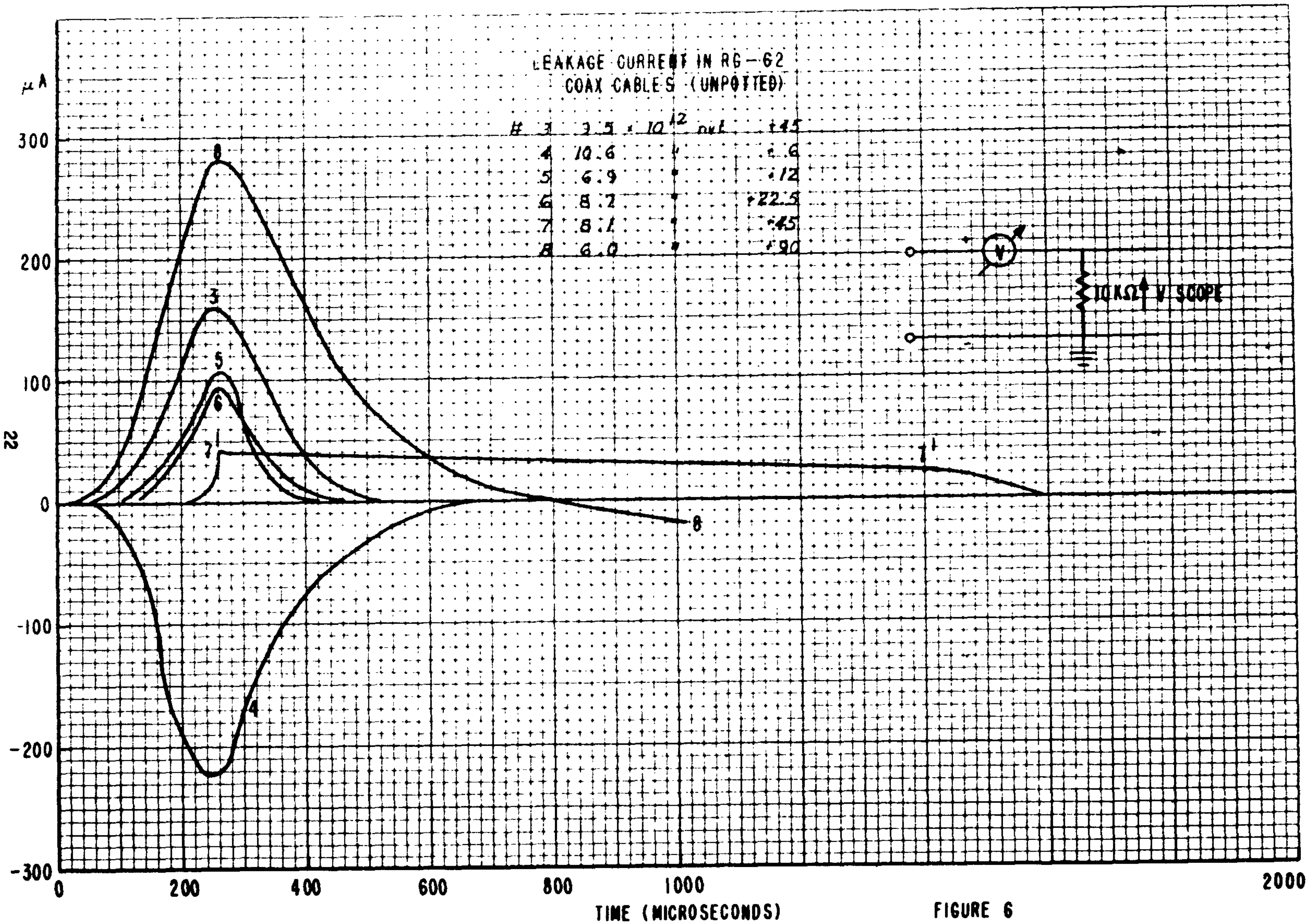

LEAKAGE CURRENT IN RG-62
COAX CABLES (UNPOTTED)
3 3.5 x 10^12 nvt +45
4 10.6 +6
5 6.9 +12
6 8.2 +22.5
7 8.1 +45
8 6.0 +90
10 KΩ
V SCOPE
μA
300
200
100
0
-100
-200
-300
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 6

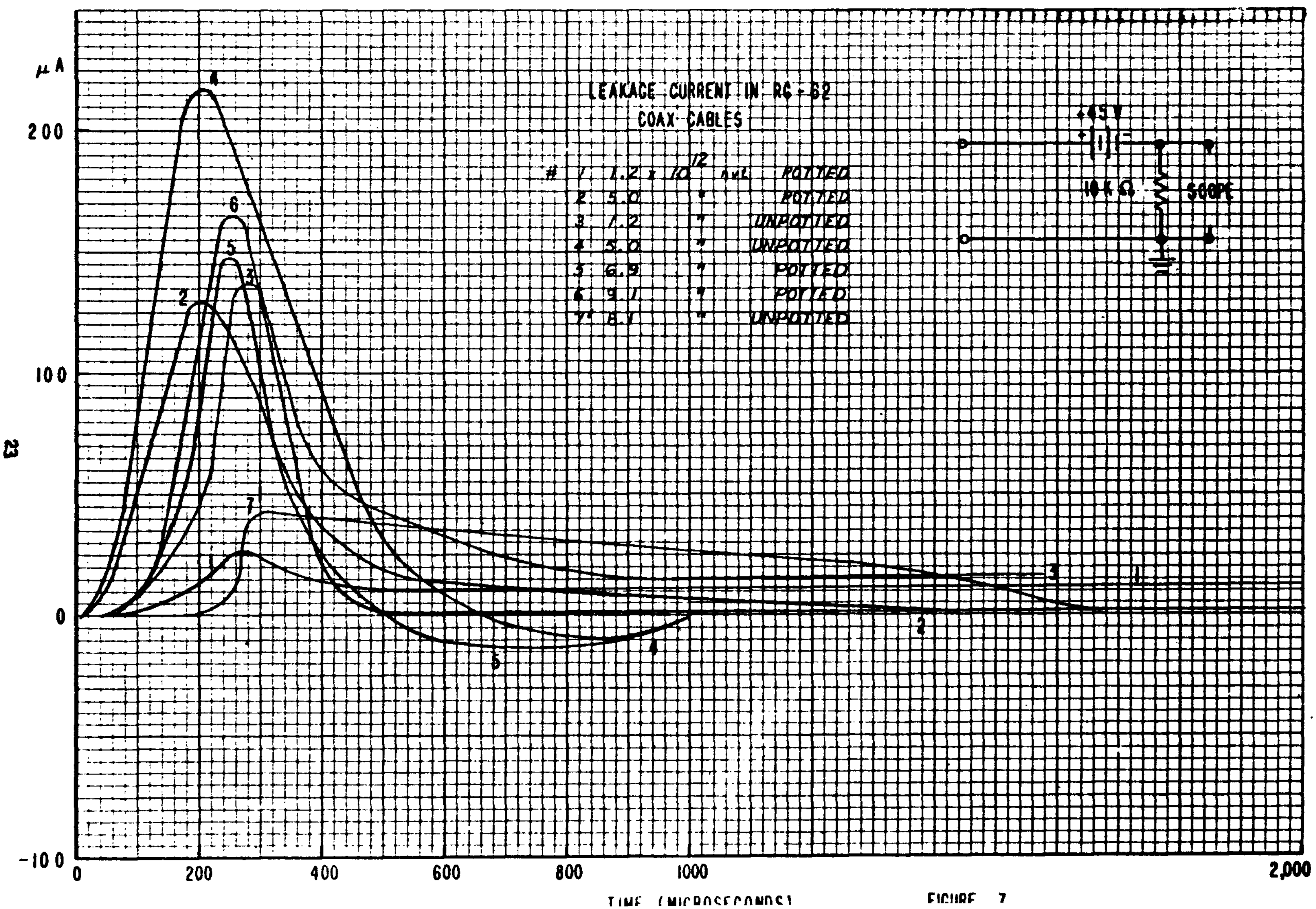
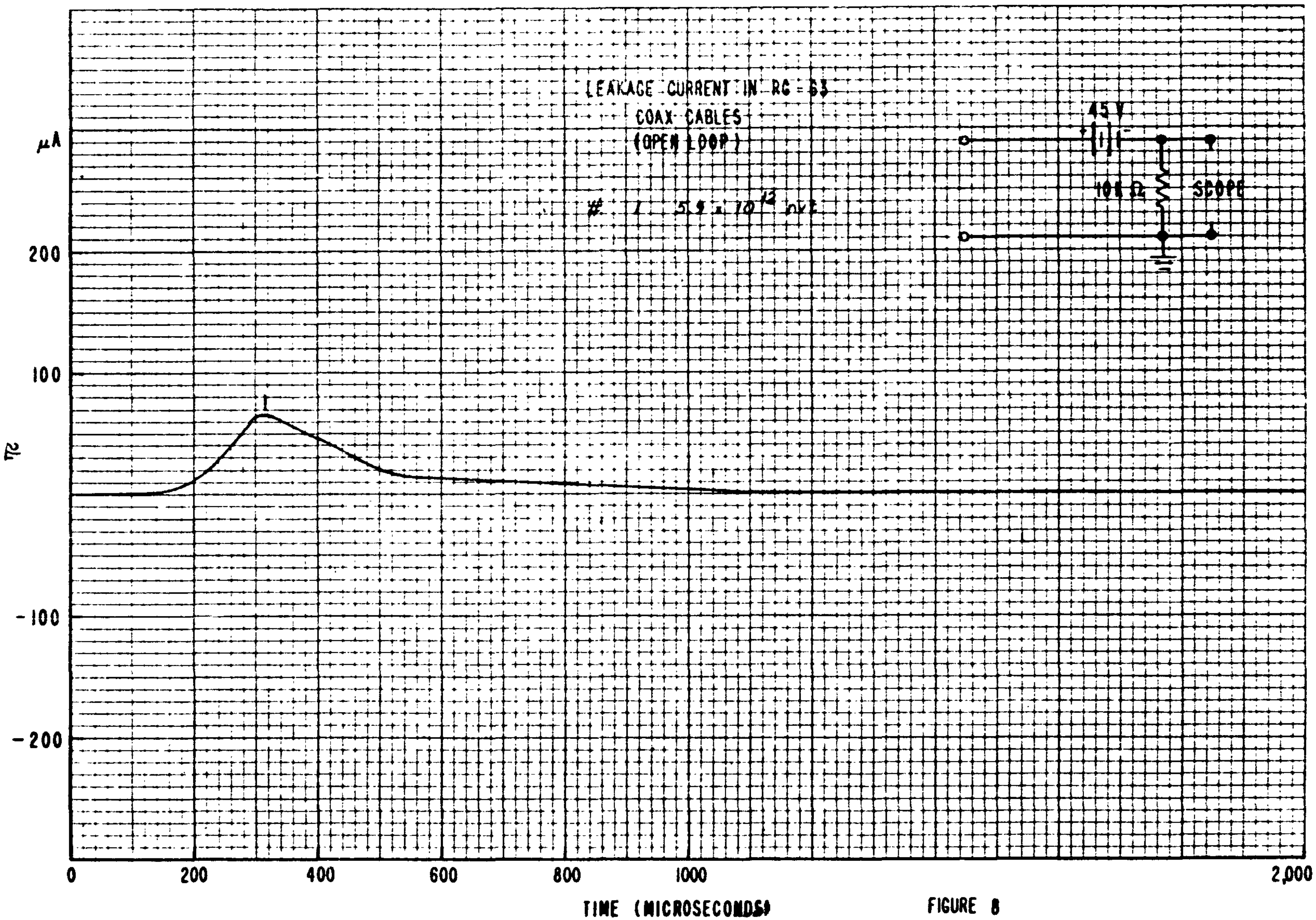
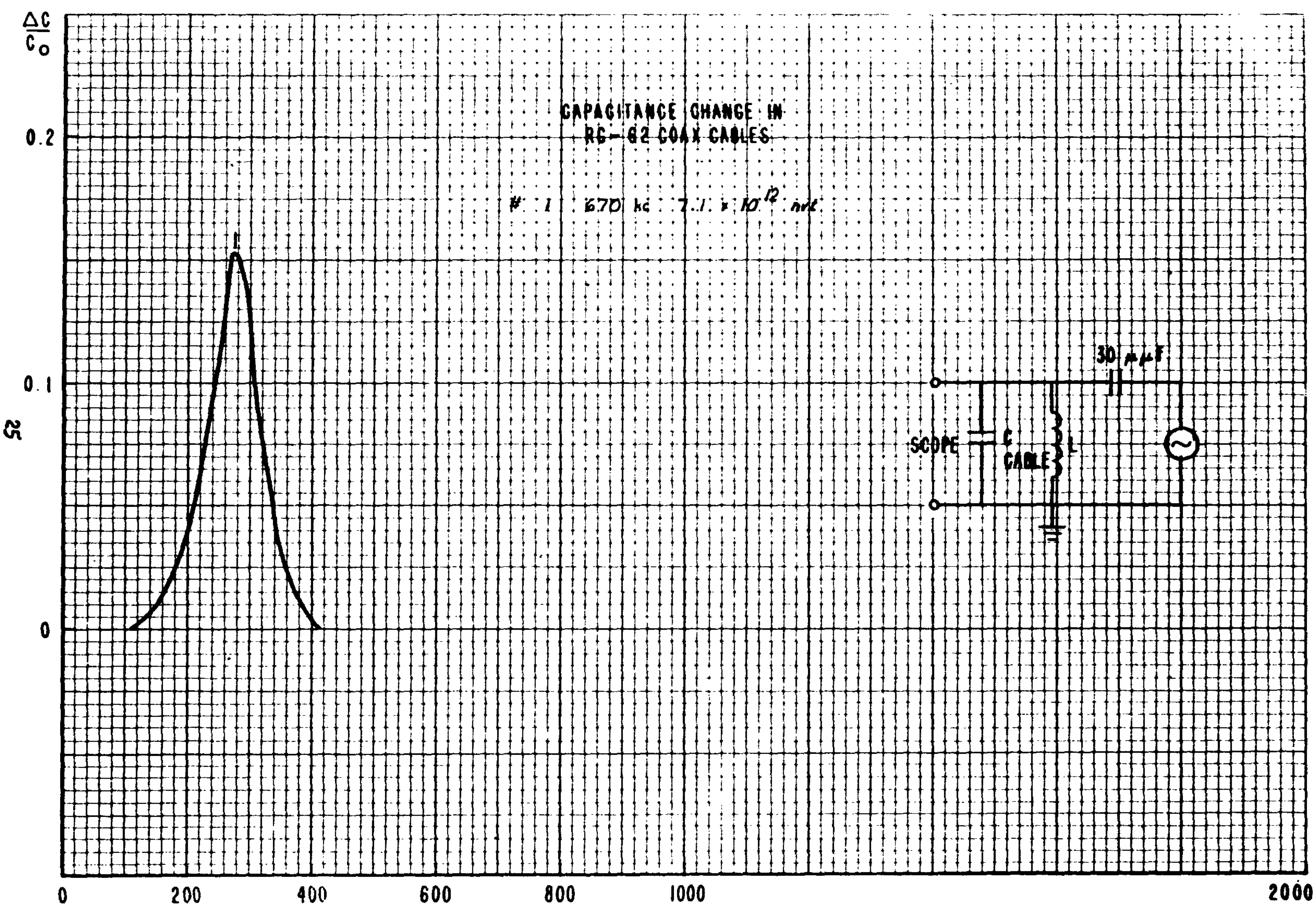

LEAKAGE CURRENT IN RG-62
COAX CABLES
1 1.2 x 10^12 ... POTTED
2 5.0 " POTTED
3 1.2 " UNPOTTED
4 5.0 " UNPOTTED
5 6.9 " POTTED
6 9.1 " POTTED
7 8.1 " UNPOTTED
+45 V
10 KΩ
500PF
μA
200
100
0
-100
0
200
400
600
800
1000
2,000
TIME (MICROSECONDS)

FIGURE 7

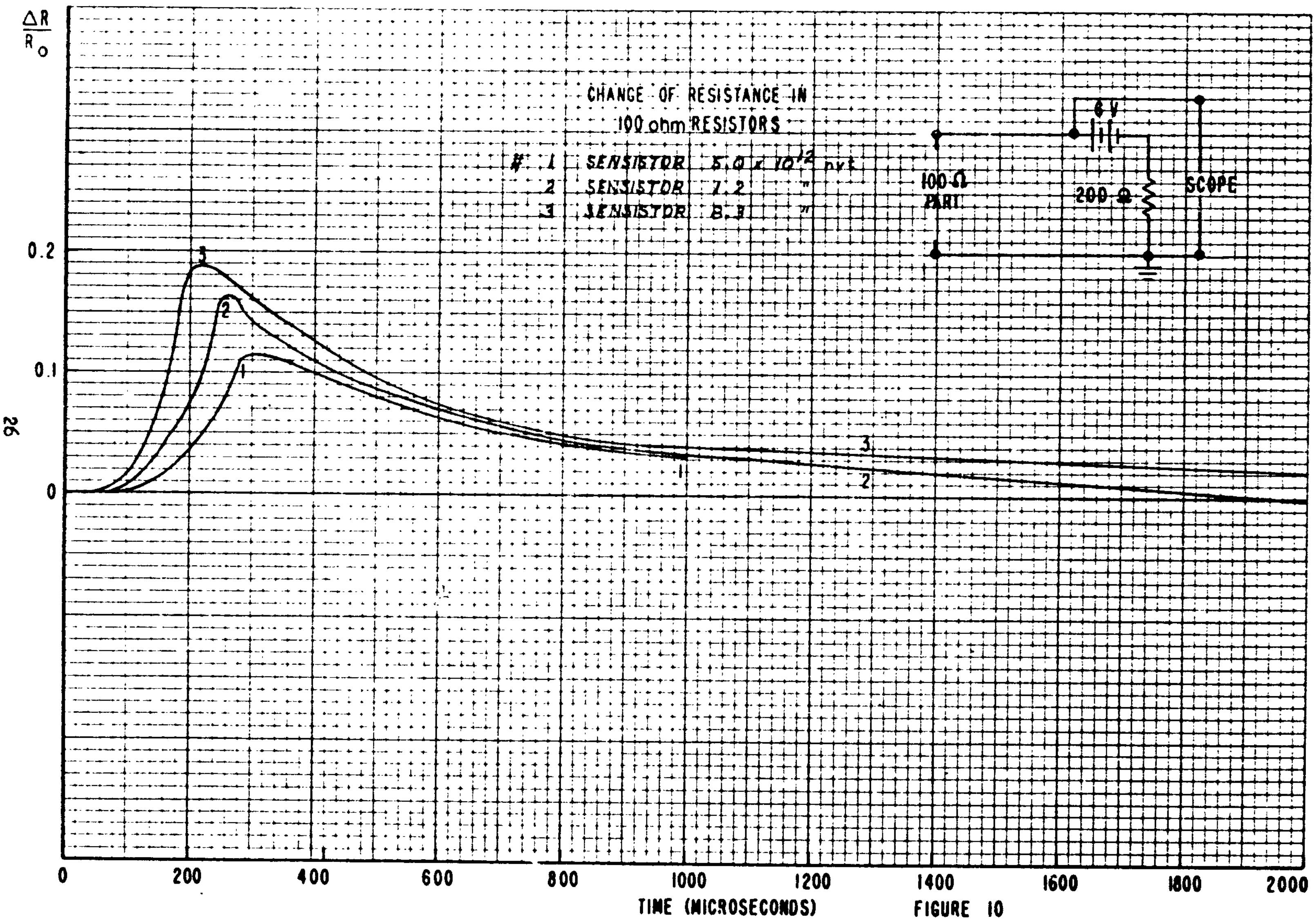


LEAKAGE CURRENT IN RG-63
COAX CABLES
(OPEN LOOP)
1 5.9 x 10^12 nvt
45 V
10^6 Ω
SCOPE
μA
200
100
-100
-200
0
200
400
600
800
1000
2,000
TIME (MICROSECONDS)

FIGURE 8

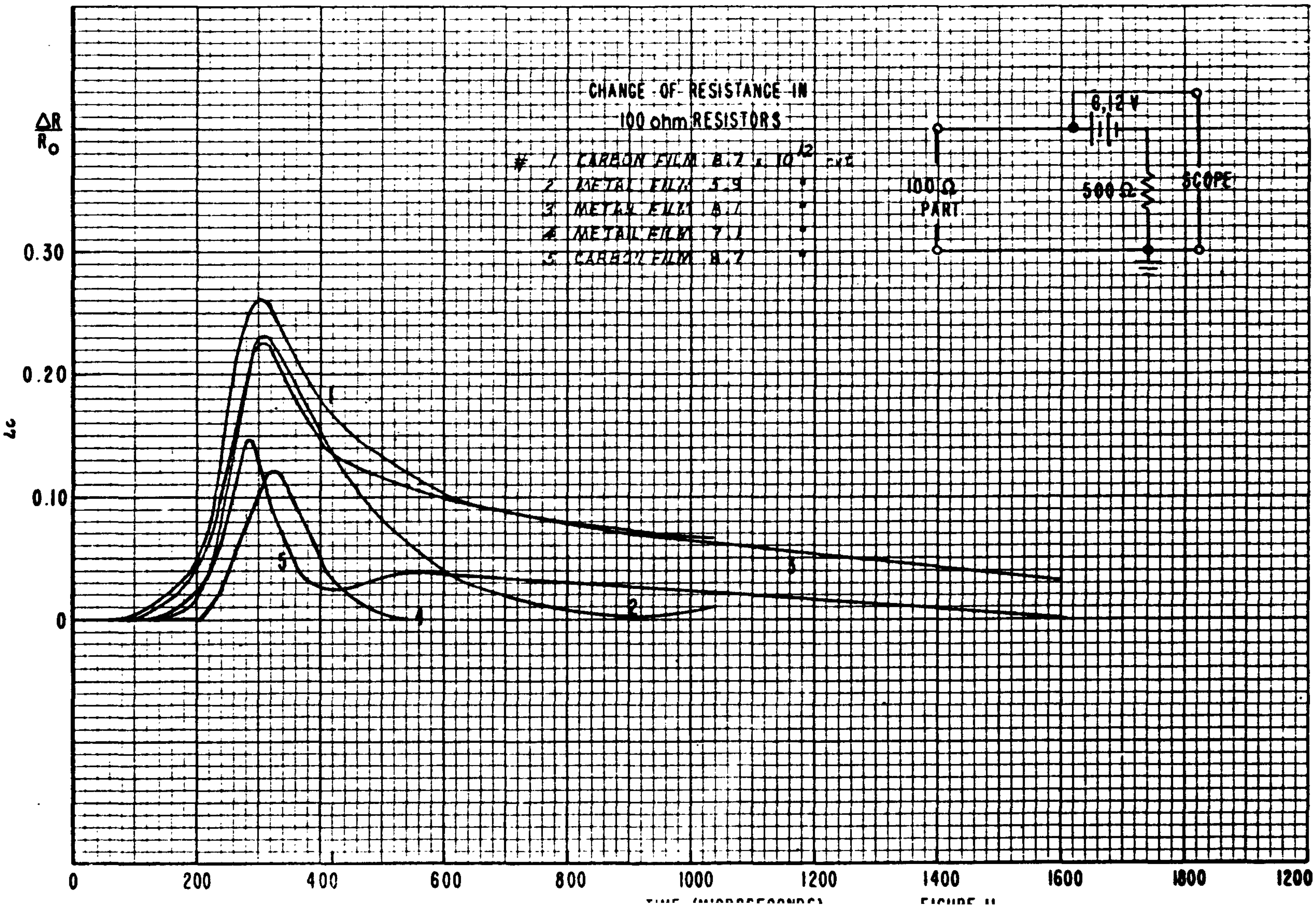


CAPACITANCE CHANGE IN
RG-62 COAX CABLES
1 670 kc 7.1 x 10^12 nvt
ΔC/Co
0.2
0.1
0
0
200
400
600
800
1000
2000
30 μμF
SCOPE
C
CABLE
L



$\frac{\Delta R}{R_o}$
0.2
0.1
0
CHANGE OF RESISTANCE IN
100 ohm RESISTORS
1 SENSISTOR 5.0 x 10^12 nvt
2 SENSISTOR 7.2 "
3 SENSISTOR 8.3 "
100 Ω
PART
6 V
200 Ω
SCOPE
1
2
3
0
200
400
600
800
1000
1200
1400
1600
1800
2000
TIME (MICROSECONDS)

FIGURE 10


CHANGE OF RESISTANCE IN
100 ohm RESISTORS
1 CARBON FILM 8.7 x 10^12
2 METAL FILM 5.9
3 METAL FILM 8.1
4 METAL FILM 7.1
5 CARBON FILM 8.7
6,12 V
100 Ω PART
500 Ω
SCOPE
ΔR/R₀
0.30
0.20
0.10
0
0
200
400
600
800
1000
1200
1400
1600
1800
1200

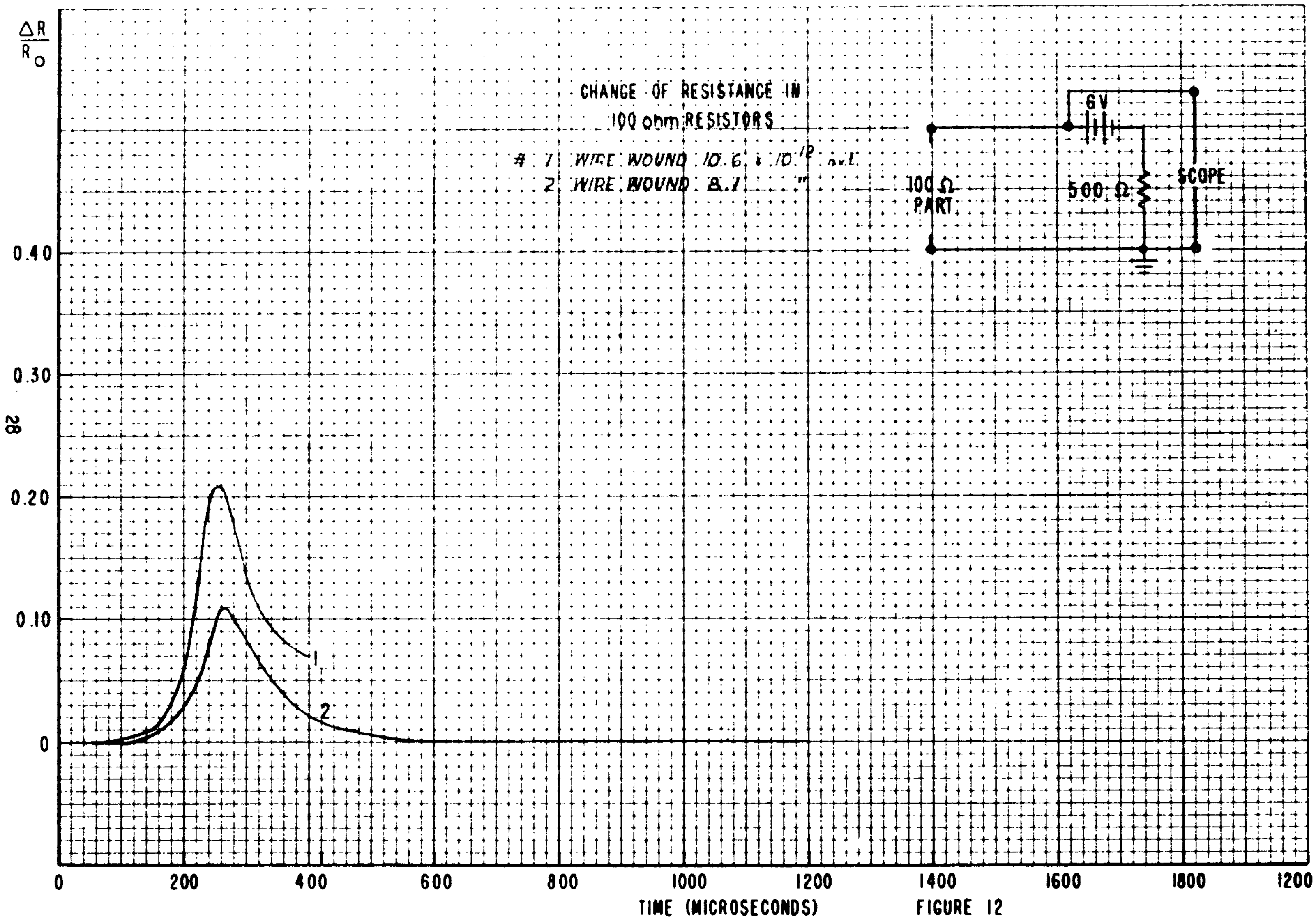
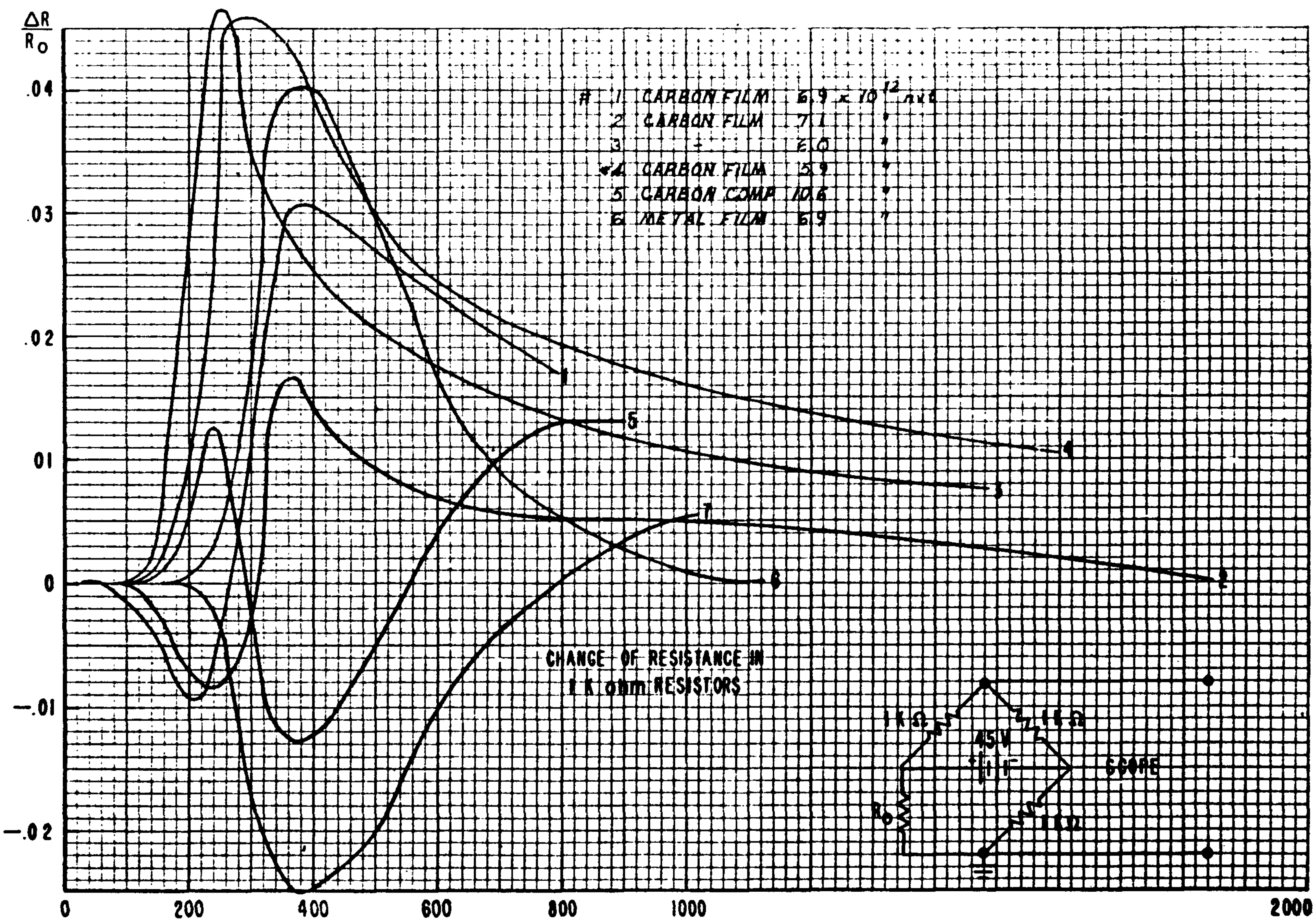

ΔR/R_o
CHANGE OF RESISTANCE IN
100 ohm RESISTORS
1 WIRE WOUND 10.6
2 WIRE WOUND 8.7 "
100 Ω PART
6V
500 Ω
SCOPE
0.40
0.30
0.20
0.10
0
1
2
0
200
400
600
800
1000
1200
1400
1600
1800
1200
TIME (MICROSECONDS)

FIGURE 12



ΔR/R_O
.04
.03
.02
.01
0
−.01
−.02
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1 CARBON FILM 6.9 × 10^12 nvt
2 CARBON FILM 7.1 "
3 " 6.0 "
4 CARBON FILM 5.9 "
5 CARBON COMP 10.6 "
6 METAL FILM 6.9 "
CHANGE OF RESISTANCE IN
1 K ohm RESISTORS
1 KΩ
1 KΩ
45 V
SCOPE
R_O
1 KΩ

FIGURE 13

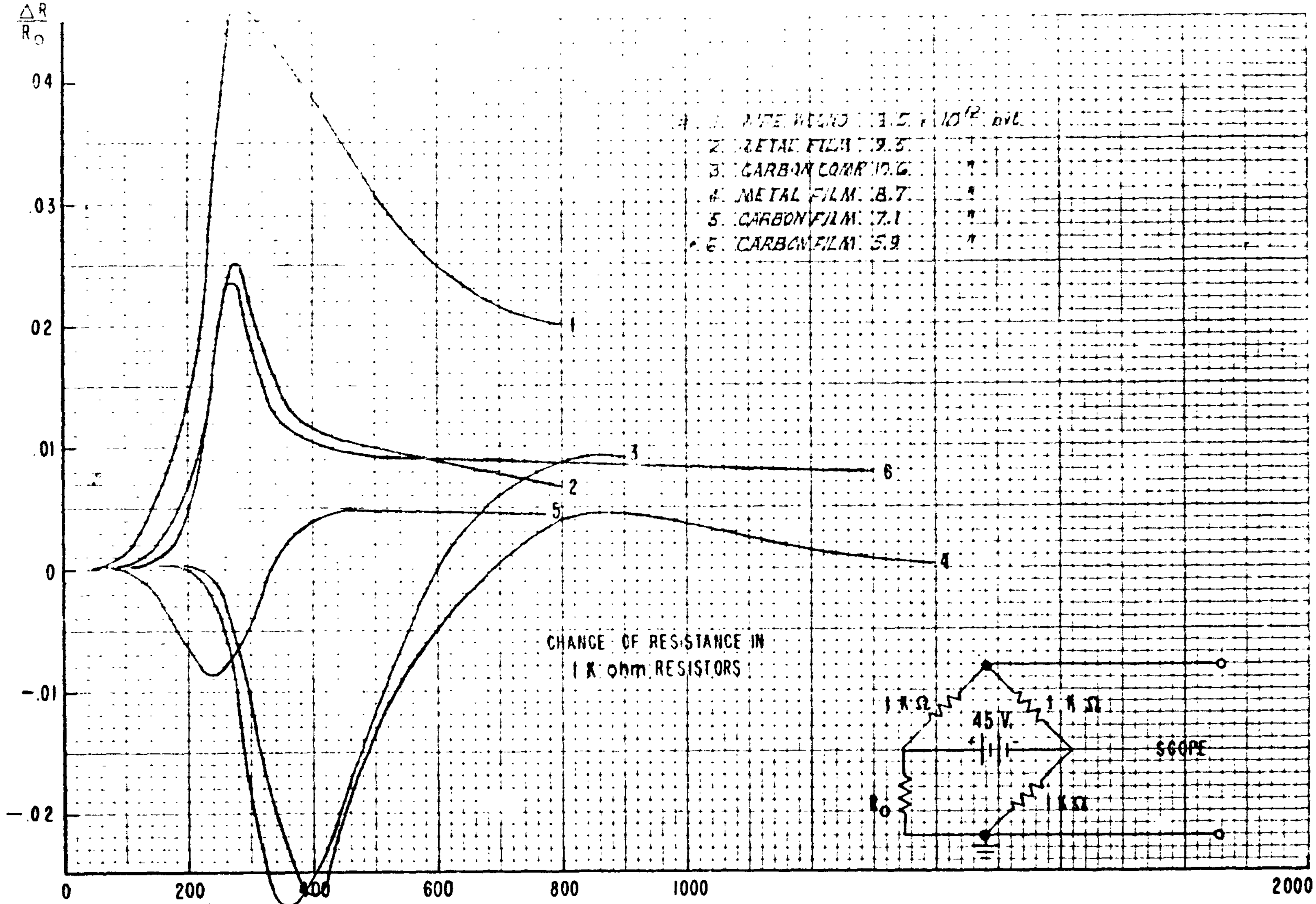
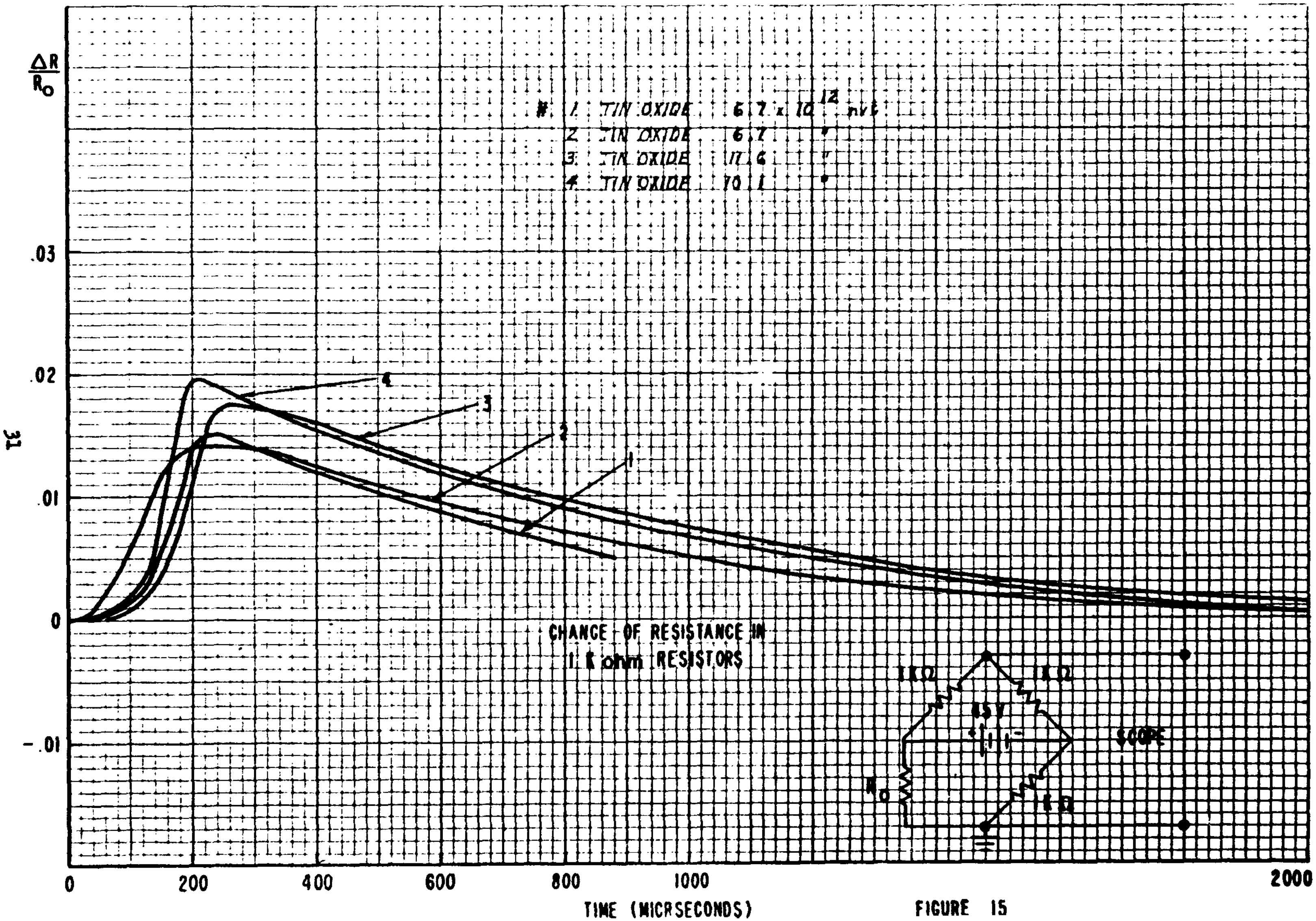
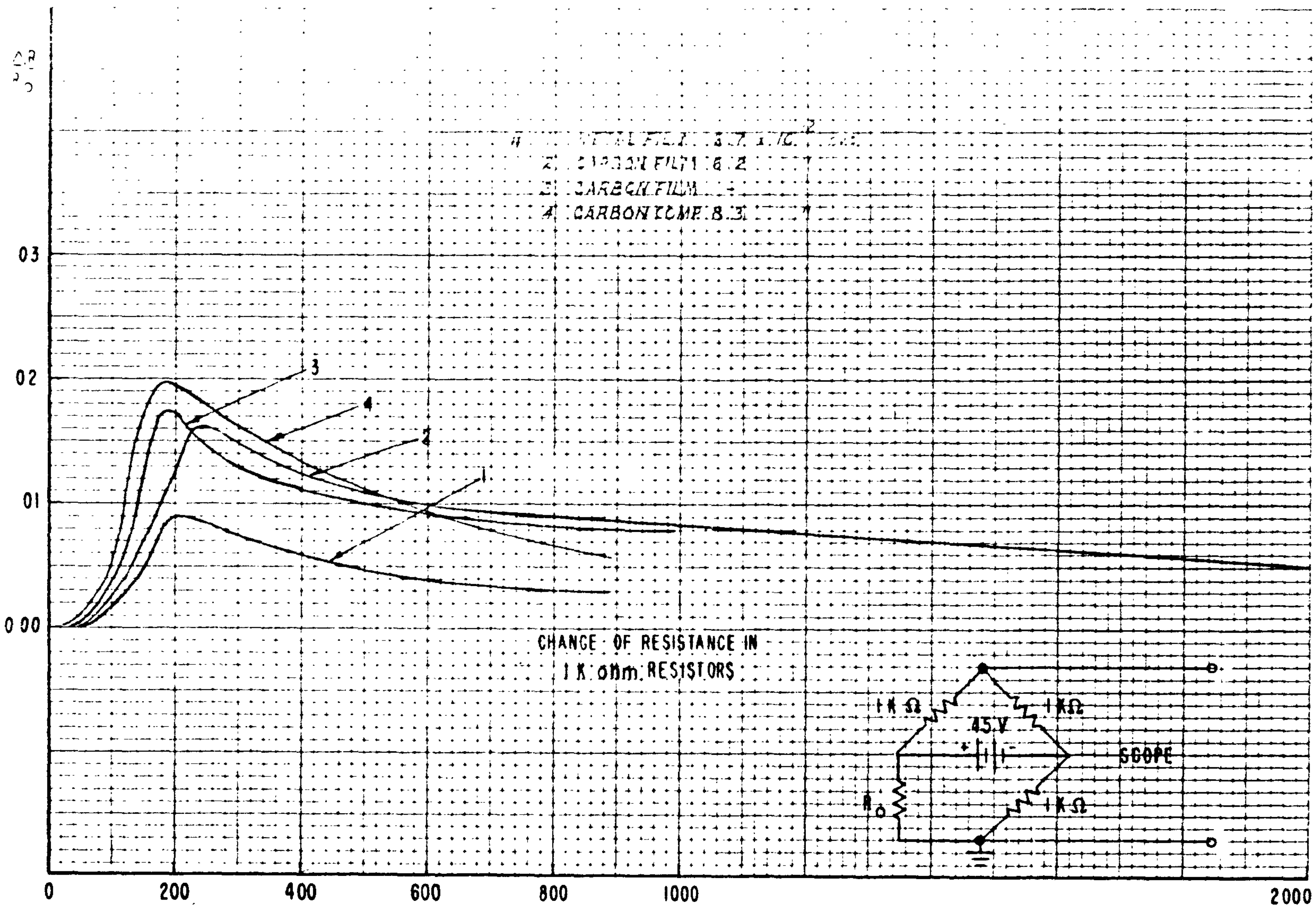

$\frac{\Delta R}{R_0}$
.04
.03
.02
.01
0
-.01
-.02
2. METAL FILM 9.5
3. CARBON COMP 10.6
4. METAL FILM 8.7
5. CARBON FILM 7.1
6. CARBON FILM 5.9
CHANGE OF RESISTANCE IN
1 K ohm RESISTORS
1 K Ω
1 K Ω
1 K Ω
45 V.
R_0
SCOPE
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 14



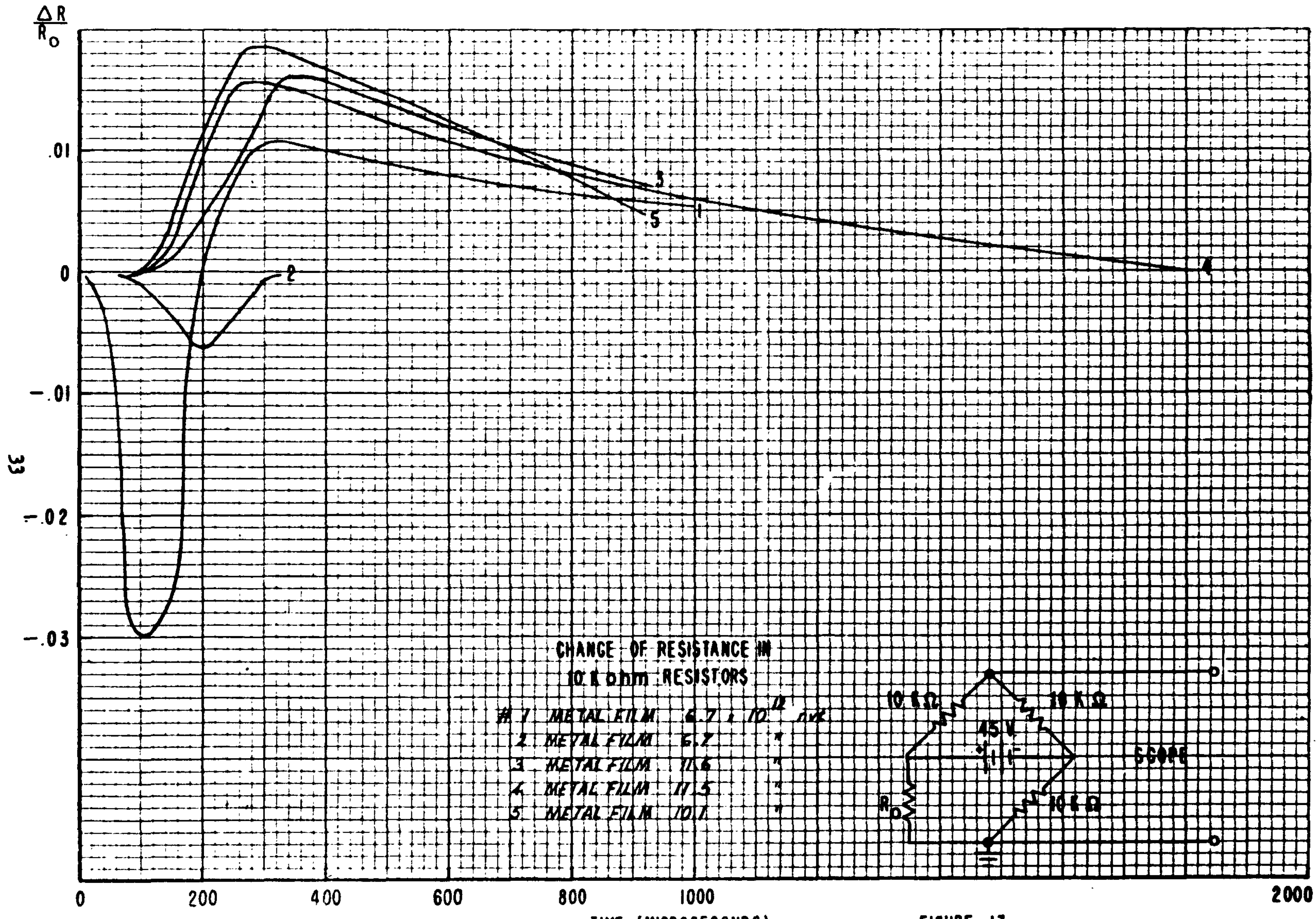
$\frac{\Delta R}{R_O}$
.03
.02
.01
0
-.01
1 TIN OXIDE 6.7 x 10^12 nvt
2 TIN OXIDE 6.7 "
3 TIN OXIDE 11.6 "
4 TIN OXIDE 70.1 "
4
3
2
1
CHANGE OF RESISTANCE IN
1 K ohm RESISTORS
1 KΩ
1 KΩ
4.5 V
SCOPE
R_O
1 KΩ
0
200
400
600
800
1000
2000
TIME (MICRSECONDS)

FIGURE 15



0 3
0 2
0 1
0 00
3
4
2
1
CARBON FILM 6.2
CARBON FILM
CARBONCOMP 8.3
CHANGE OF RESISTANCE IN
1 K ohm RESISTORS
1 K Ω
1 K Ω
45 V
SCOPE
R_o
1 K Ω
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 16



CHANGE OF RESISTANCE IN
10 K ohm RESISTORS
1 METAL FILM 6.7 x 10^12 nvt
2 METAL FILM 6.7
3 METAL FILM 11.6
4 METAL FILM 11.5
5 METAL FILM 10.1
10 K Ω
10 K Ω
10 K Ω
45 V
SCOPE
R_o
$\frac{\Delta R}{R_o}$
.01
0
-.01
-.02
-.03
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 17

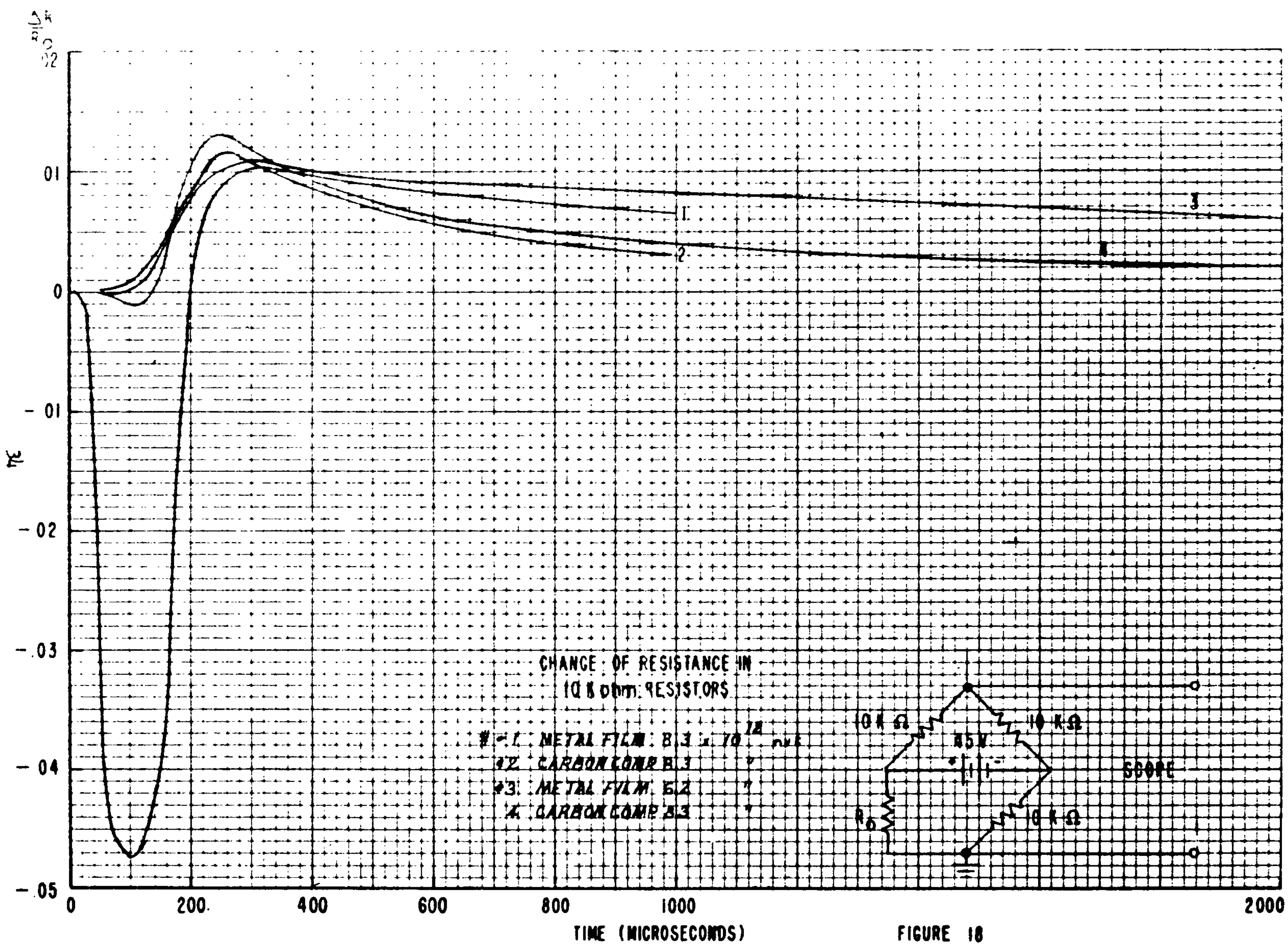
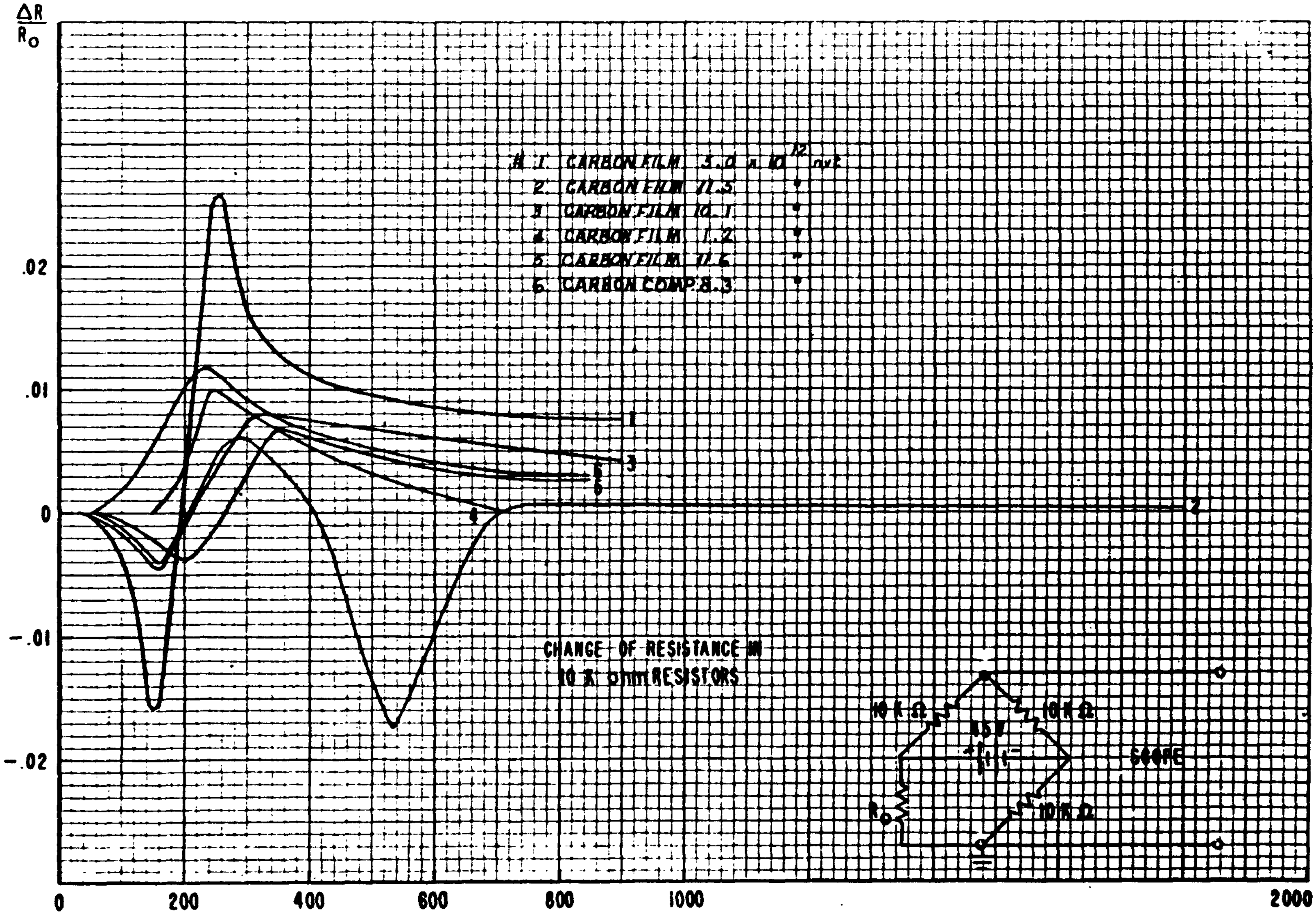

.02
.01
0
-.01
-.02
-.03
-.04
-.05
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
CHANGE OF RESISTANCE IN
10 K ohm RESISTORS
#1 METAL FILM
#2 CARBON COMP
#3 METAL FILM
4 CARBON COMP
10 K Ω
10 K Ω
10 K Ω
SCOPE

FIGURE 18



$\frac{\Delta R}{R_0}$
.02
.01
0
-.01
-.02
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1 CARBON FILM 3.0 x 10^{12} nvt
2 CARBON FILM 11.5 "
3 CARBON FILM 10.1 "
4 CARBON FILM 1.2 "
5 CARBON FILM 11.6 "
6 CARBON COMP 8.3 "
CHANGE OF RESISTANCE IN
10 K ohm RESISTORS
10 K Ω
10 K Ω
10 K Ω
R_0
SCOPE
1
2
3
4
5
6

FIGURE 19

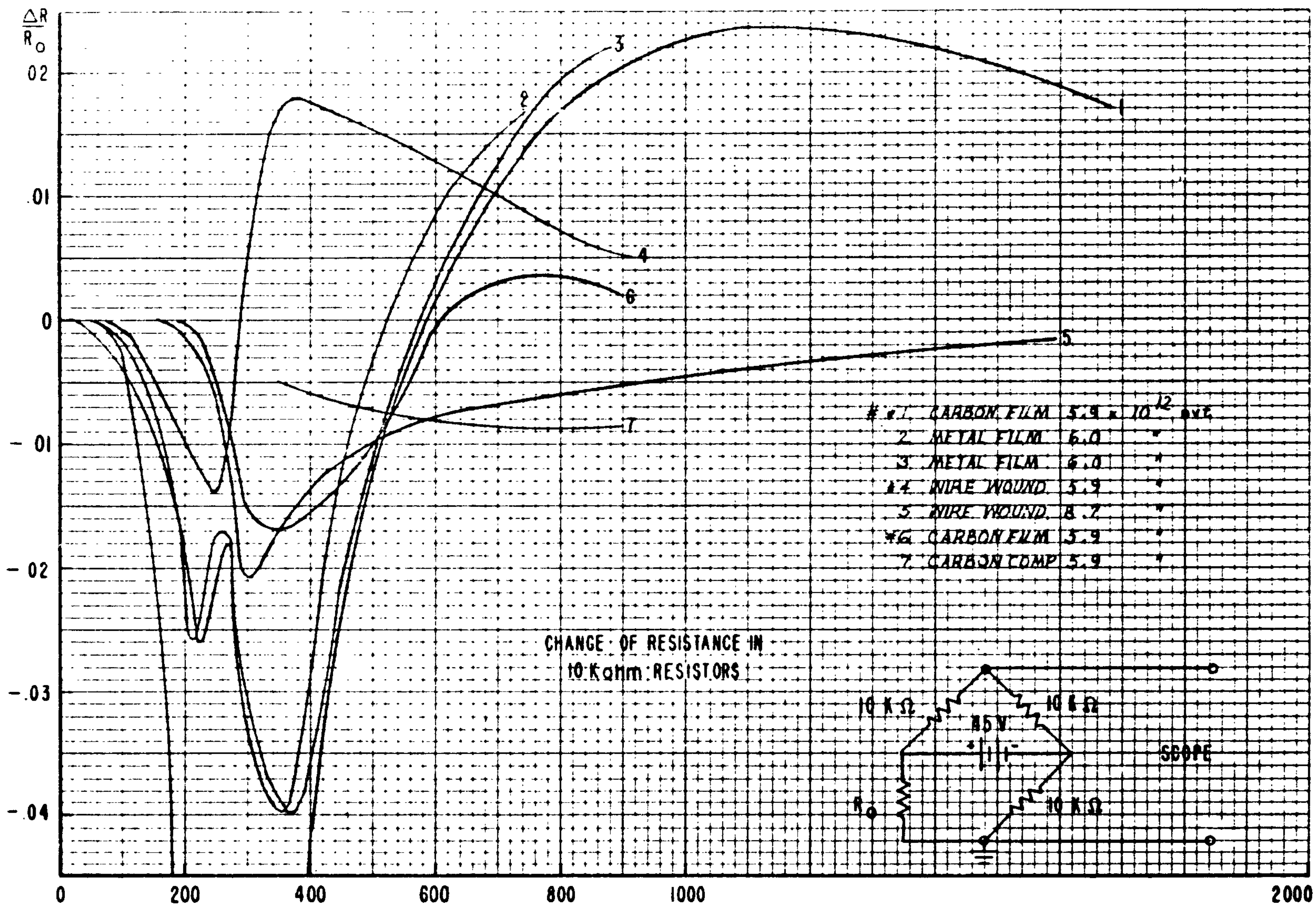
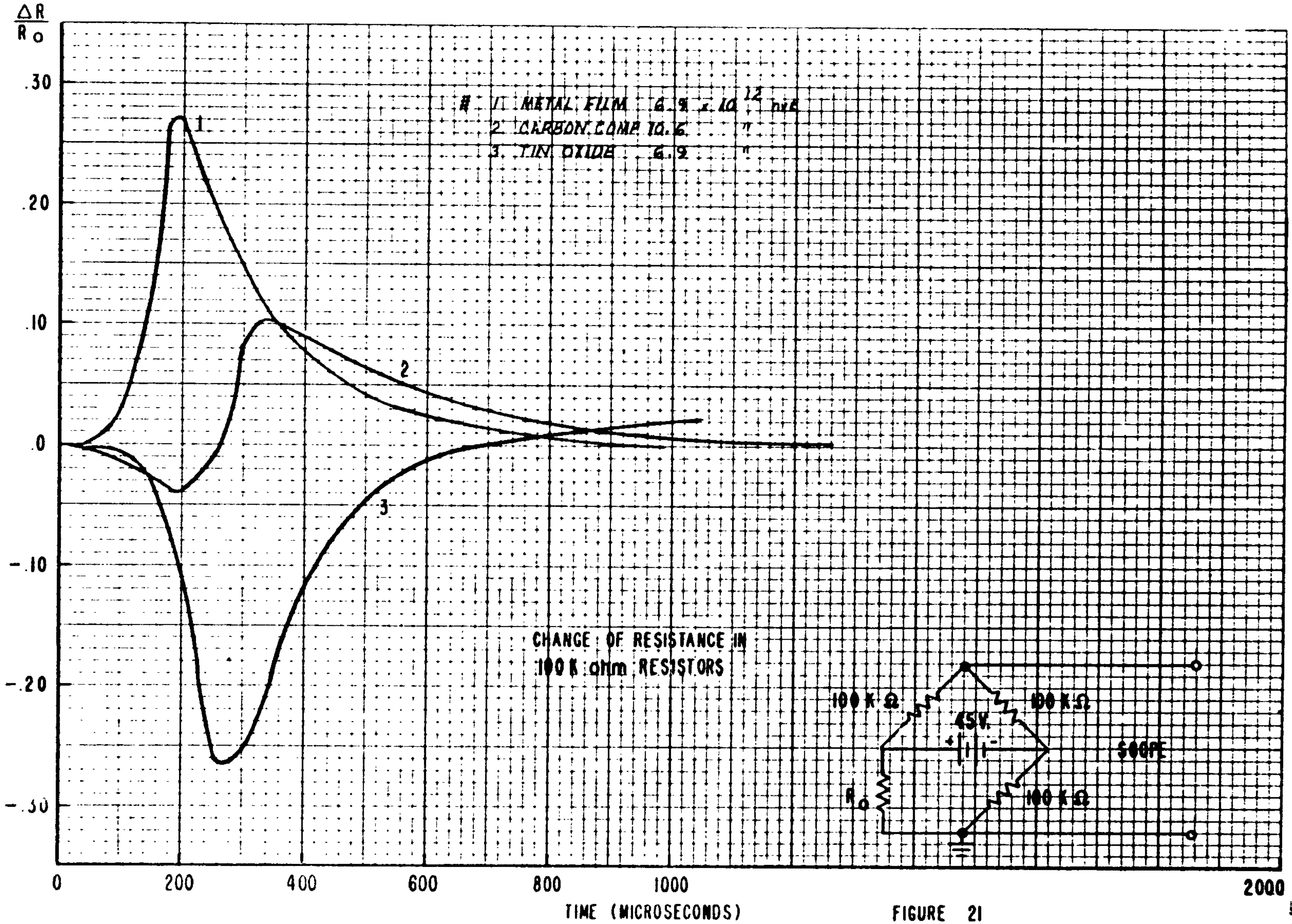

ΔR/R_O
.02
.01
0
-.01
-.02
-.03
-.04
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1
2
3
4
5
6
7
1. CARBON FILM 5.9 x 10^12 nvt
2. METAL FILM 6.0
3. METAL FILM 6.0
4. WIRE WOUND 5.9
5. WIRE WOUND 8.7
6. CARBON FILM 5.9
7. CARBON COMP 5.9
CHANGE OF RESISTANCE IN
10 Kohm RESISTORS
10 K Ω
10 K Ω
10 K Ω
45 V
R_O
SCOPE

FIGURE 20



$\frac{\Delta R}{R_o}$
.30
.20
.10
.0
-.10
-.20
-.30
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1 METAL FILM 6.9 x 10^12 nvt
2 CARBON COMP 10.6 "
3 TIN OXIDE 6.9 "
1
2
3
CHANGE OF RESISTANCE IN
100 K ohm RESISTORS
100 K Ω
100 K Ω
100 K Ω
45V
R_o
SCOPE

FIGURE 21

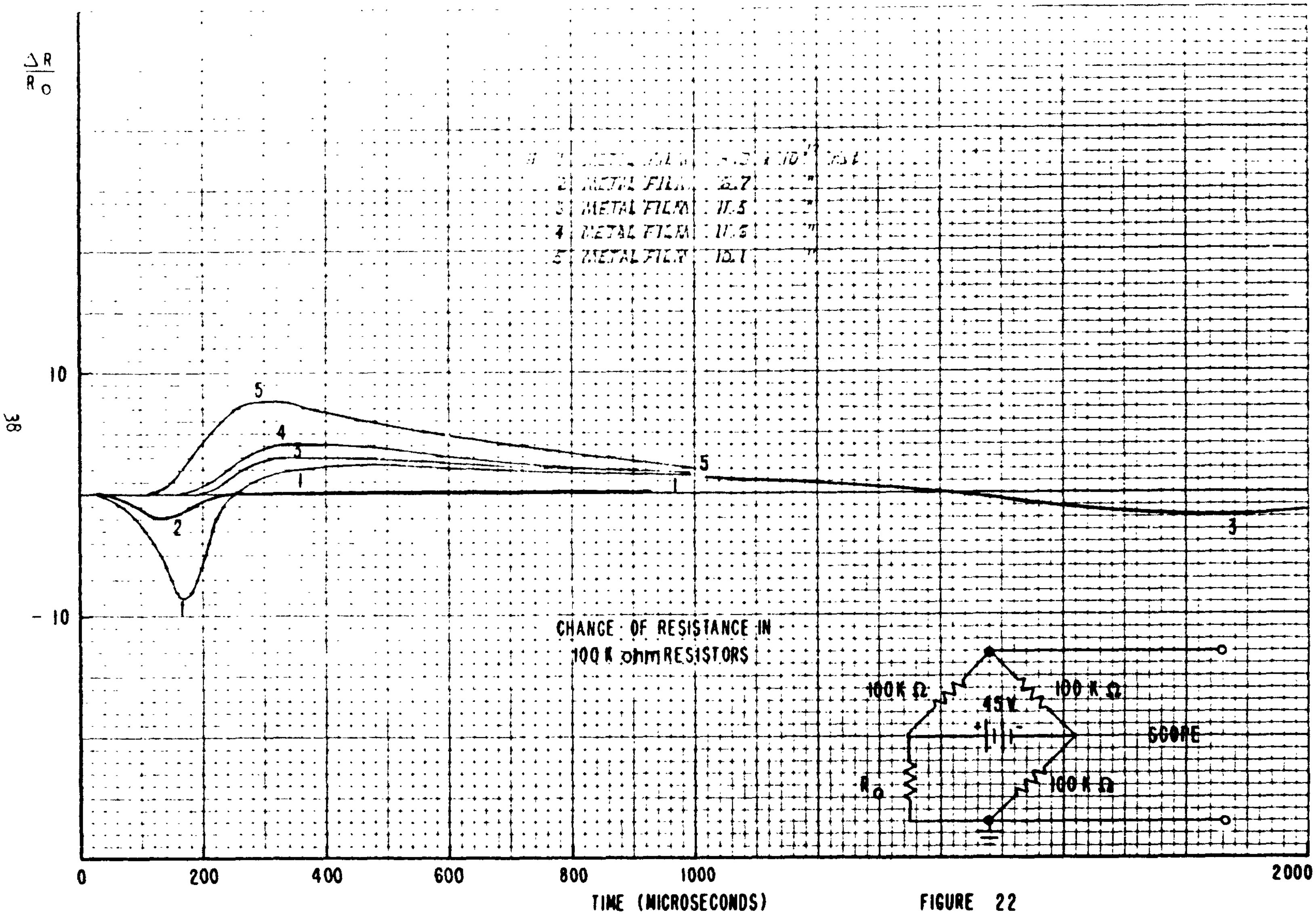

ΔR / R o
10
- 10
CHANGE OF RESISTANCE IN
100 K ohm RESISTORS
100 K Ω
100 K Ω
45 V
SCOPE
R o
100 K Ω
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 22

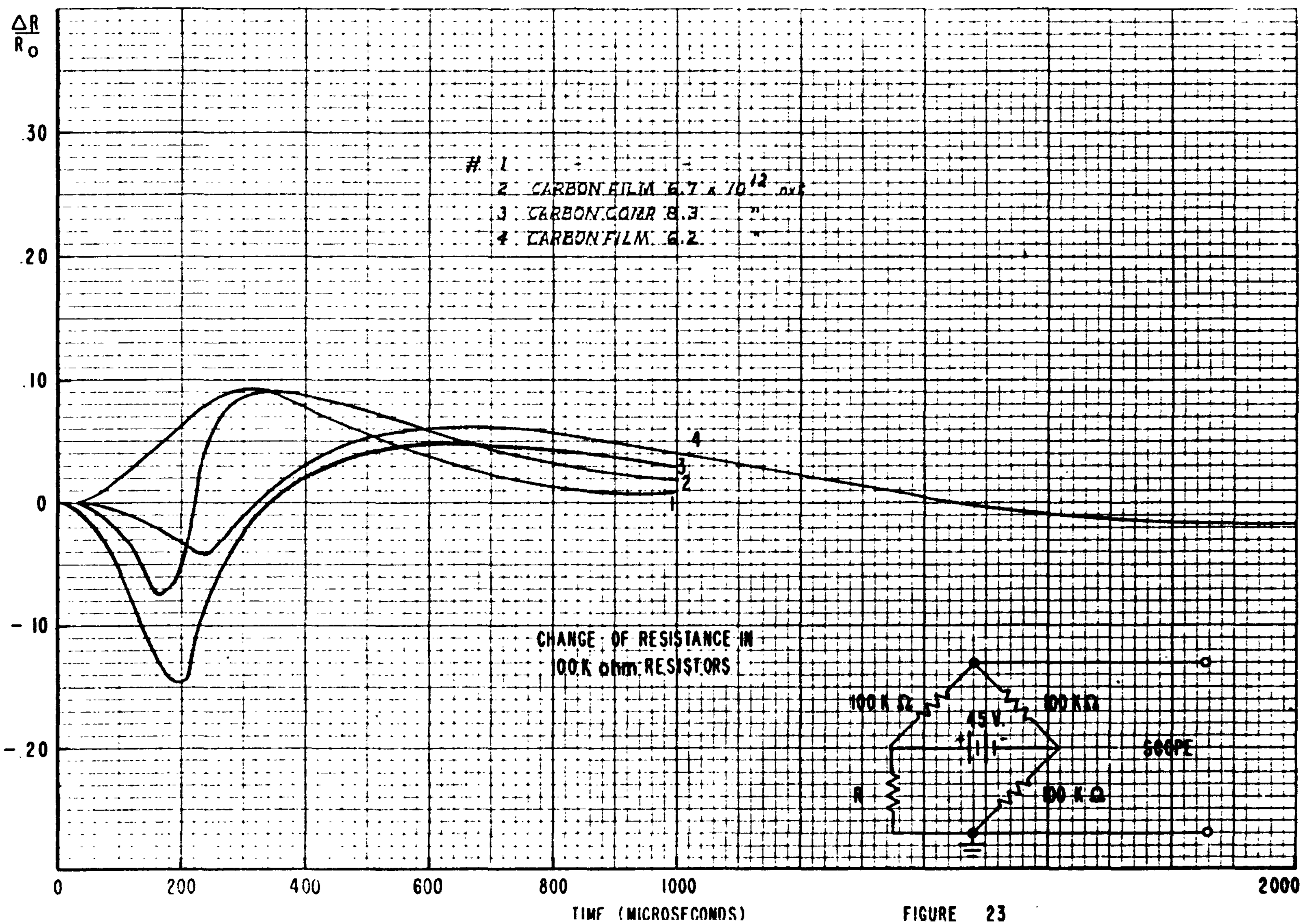
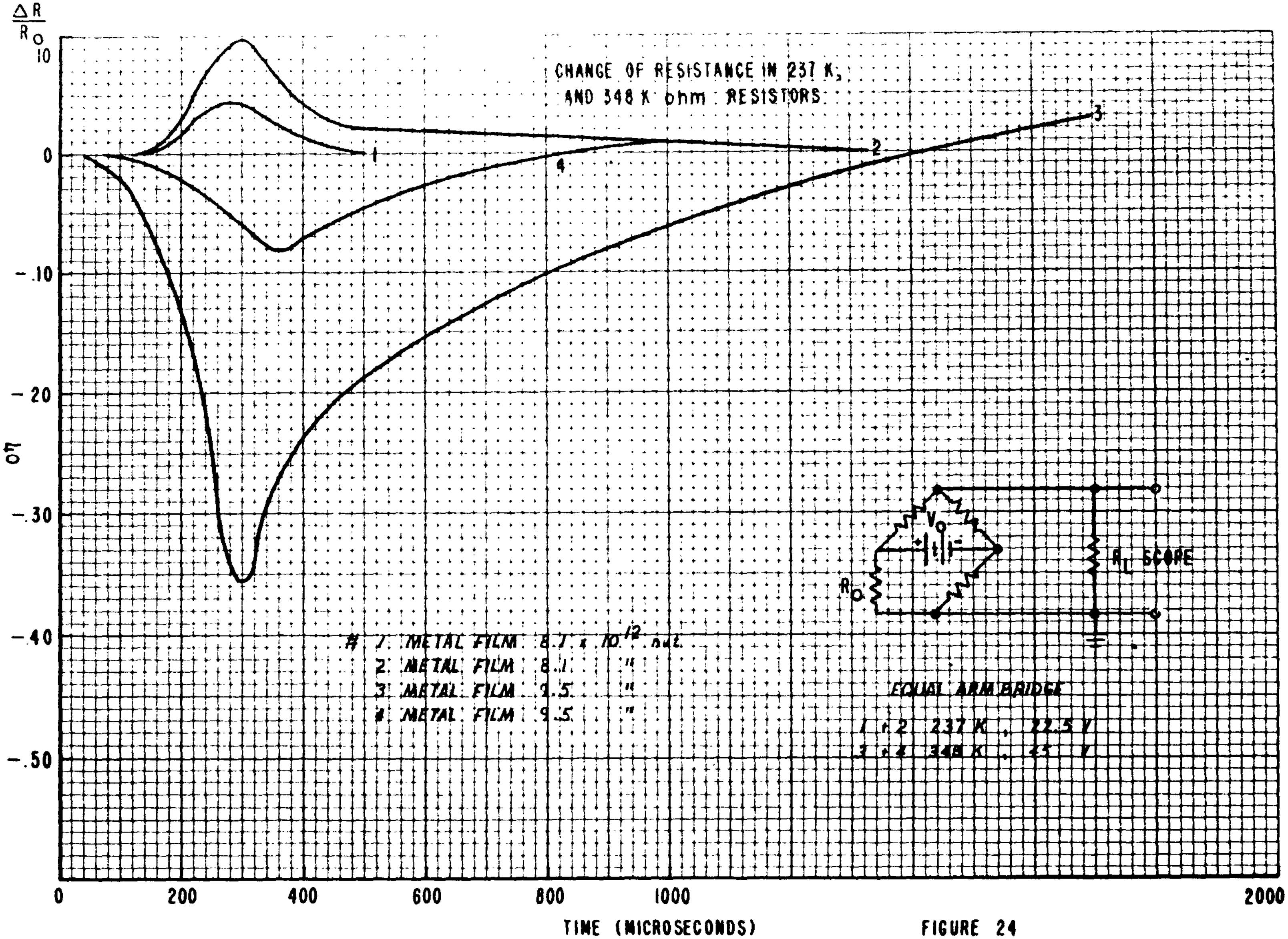

ΔR / R_O
.30
.20
.10
0
- 10
- .20
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1
2 CARBON FILM 6.7 x 10^12 nvt
3 CARBON COMP 8.3 "
4 CARBON FILM 6.2 "
1
2
3
4
CHANGE OF RESISTANCE IN
100 K ohm RESISTORS
100 K Ω
100 K Ω
100 K Ω
45 V.
R
SCOPE

FIGURE 23



CHANGE OF RESISTANCE IN 237 K, AND 348 K ohm RESISTORS
ΔR/Ro
10
0
-.10
-.20
-.30
-.40
-.50
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1 METAL FILM 8.7 x 10^12 n.v.t.
2 METAL FILM 8.1 "
3 METAL FILM 9.5 "
4 METAL FILM 9.5 "
Vo
Ro
RL SCOPE
EQUAL ARM BRIDGE
1 + 2 237 K , 22.5 V
3 + 4 348 K , 45 V

FIGURE 24

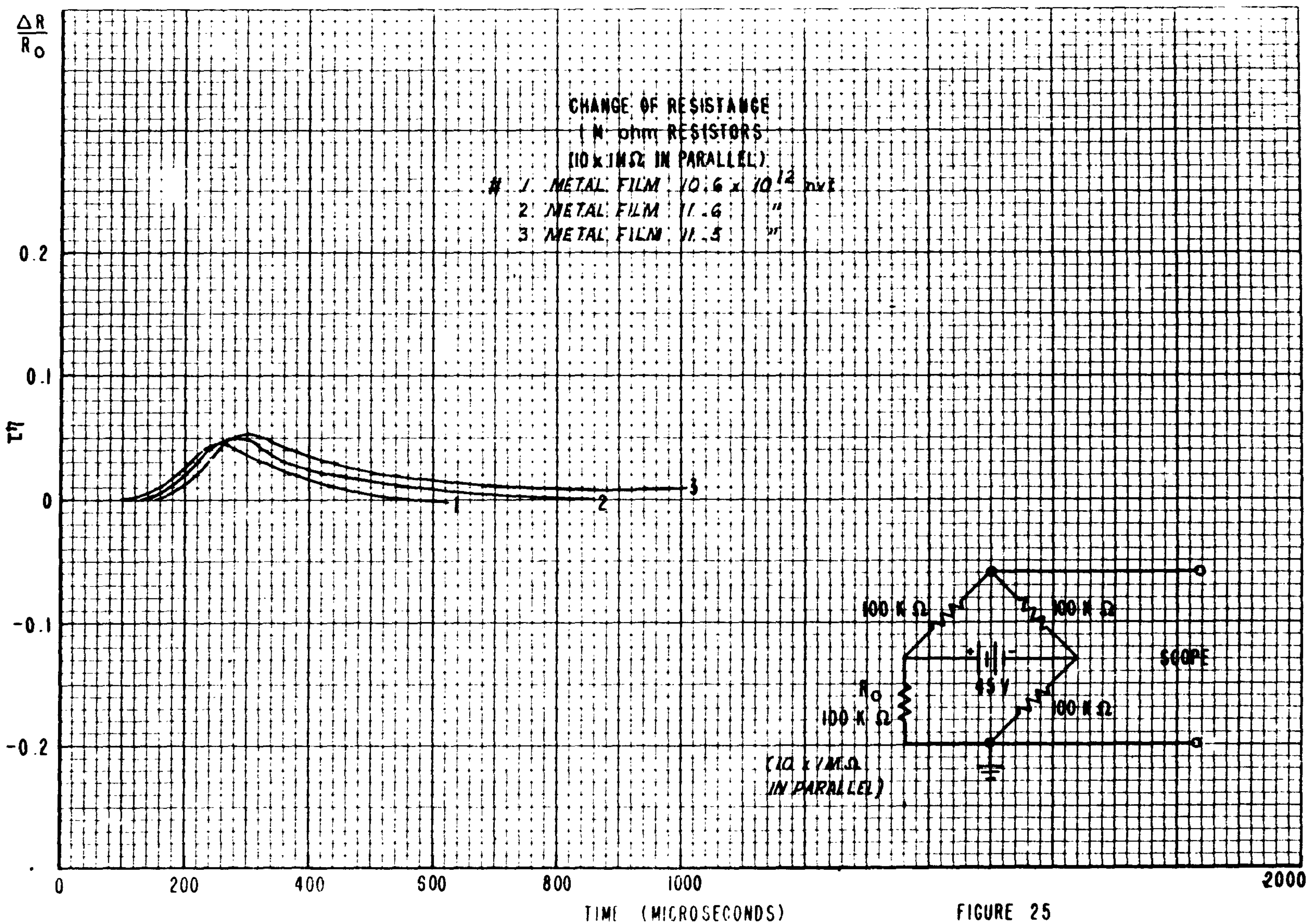
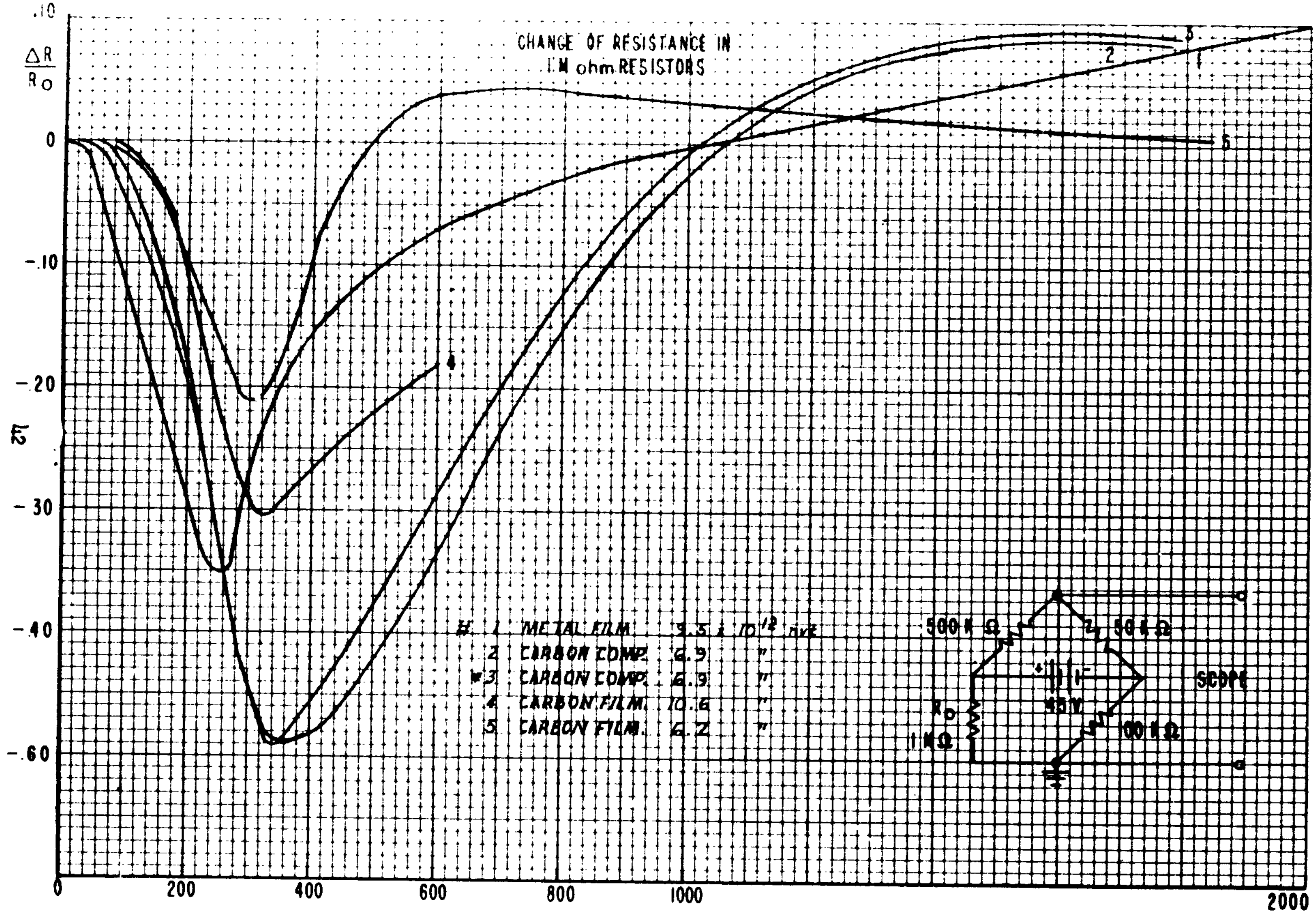

CHANGE OF RESISTANCE
1 M ohm RESISTORS
(10 x 1MΩ IN PARALLEL)
1 METAL FILM 10.6 x 10^12 nvt
2 METAL FILM 11.6 "
3 METAL FILM 11.5 "
ΔR/Ro
0.2
0.1
0
-0.1
-0.2
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1
2
3
100 K Ω
100 K Ω
100 K Ω
Ro
100 K Ω
45 V
SCOPE
(10 x 1M Ω
IN PARALLEL)

FIGURE 25



CHANGE OF RESISTANCE IN
1 M ohm RESISTORS
.10
ΔR/Ro
0
-.10
-.20
-.30
-.40
-.60
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1 METAL FILM 9.5 x 10^12 nvt
2 CARBON COMP. 6.9 "
*3 CARBON COMP. 6.9 "
4 CARBON FILM 10.6 "
5 CARBON FILM 6.2 "
500 K Ω
50 K Ω
45 V
SCOPE
Ro
1 MΩ
100 K Ω
1
2
3
4
5

FIGURE 26

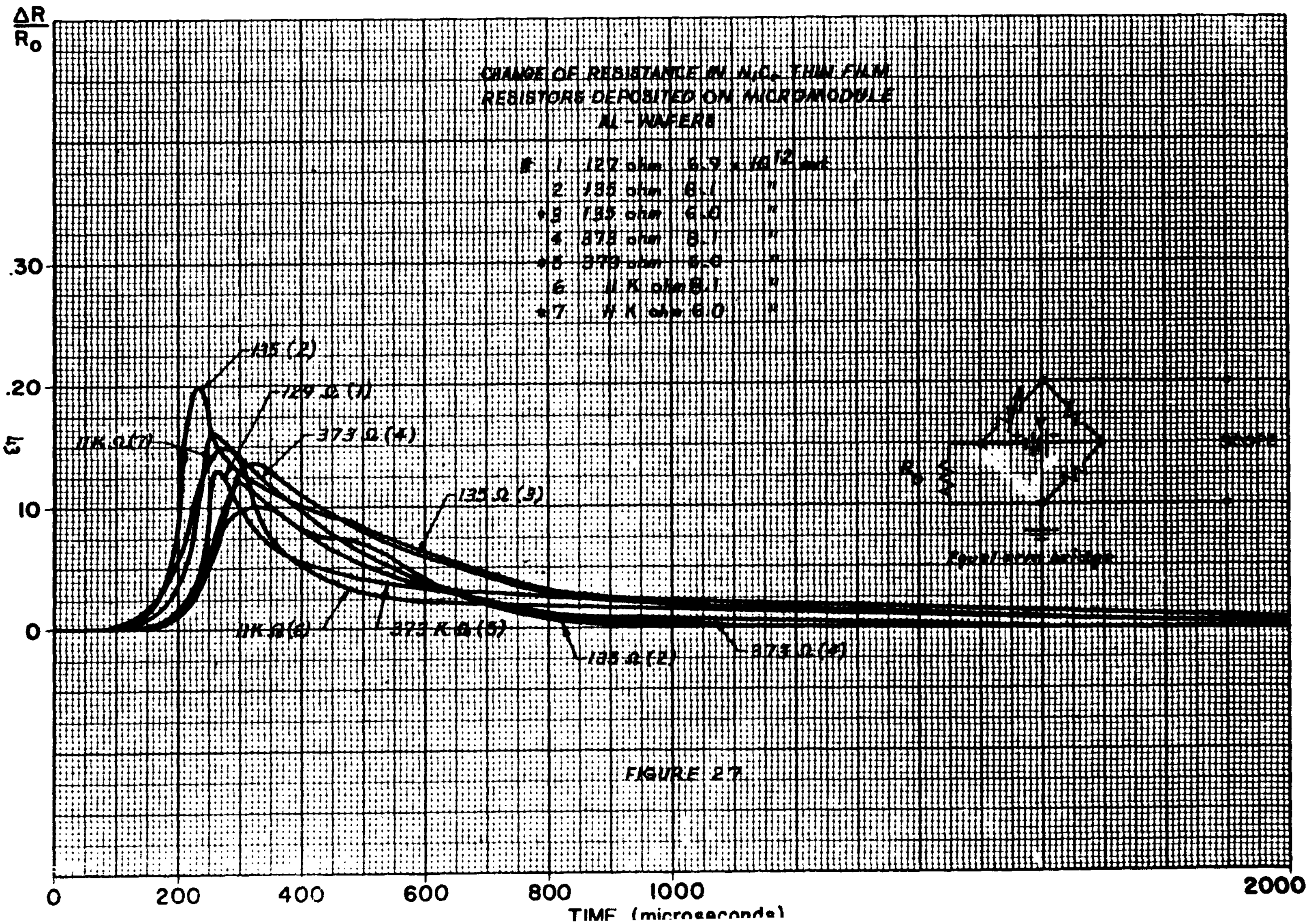
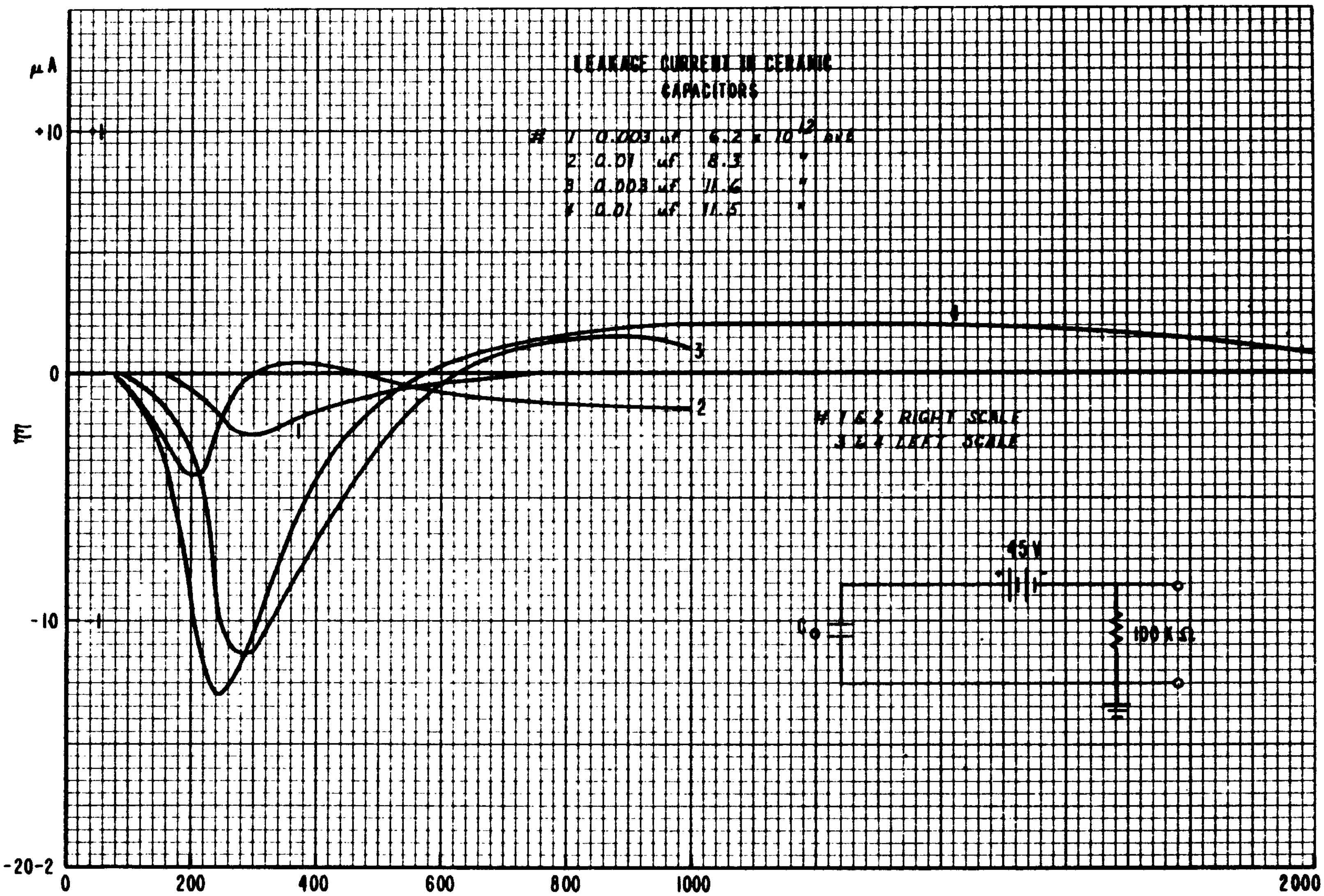
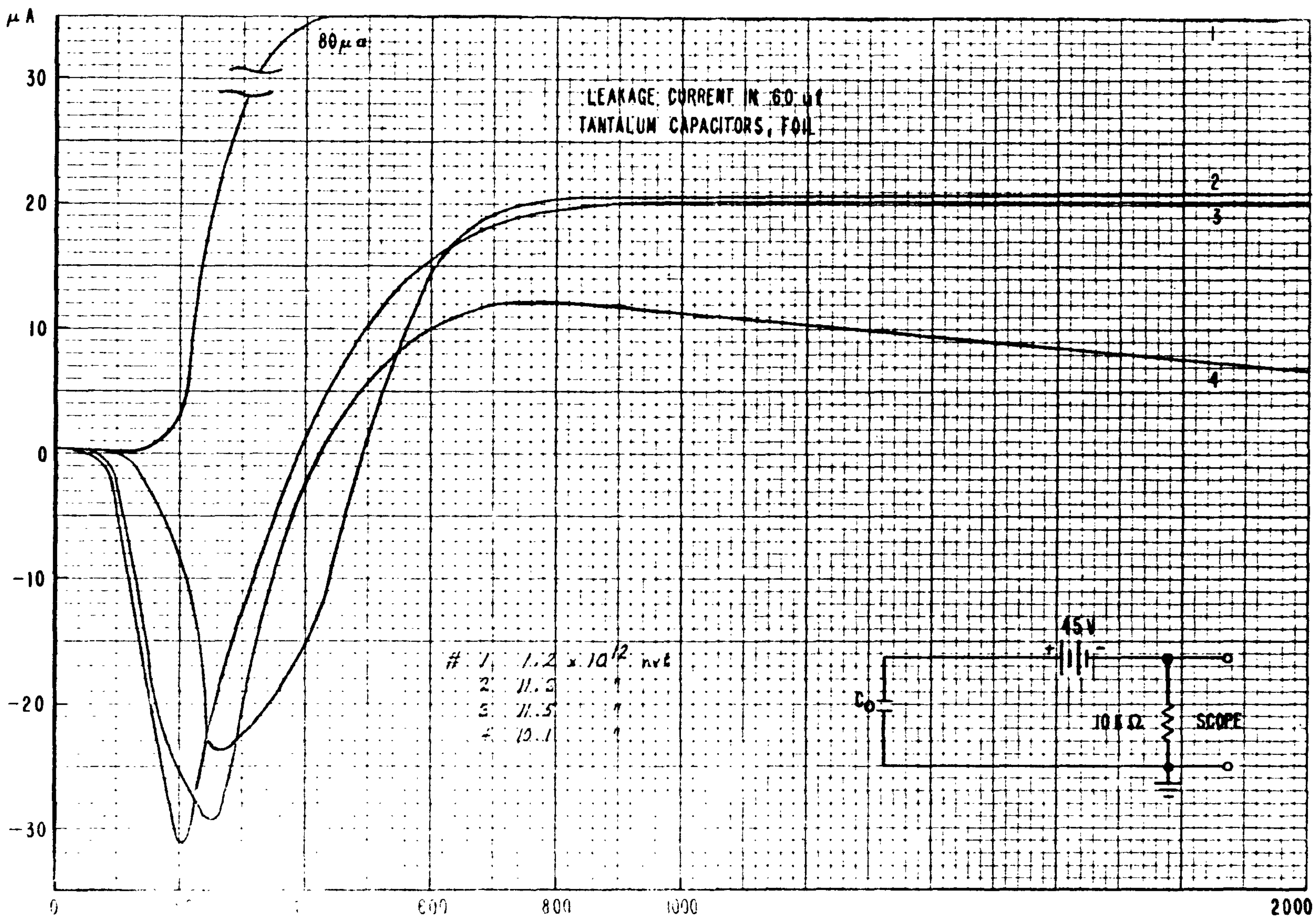

CHANGE OF RESISTANCE IN NiCr THIN FILM
RESISTORS DEPOSITED ON MICROMODULE
AL - WAFERS
1 127 ohm 6.9 x 10^12
2 135 ohm 8.1 "
*3 135 ohm 6.0 "
4 373 ohm 8.1 "
*5 373 ohm 6.0 "
6 11 K ohm 8.1 "
*7 11 K ohm 6.0 "
135 (2)
129 Ω (1)
373 Ω (4)
11K Ω (7)
135 Ω (3)
11K Ω (6)
373 K Ω (5)
135 Ω (2)
373 Ω (4)
Equal arm bridge
ΔR/R0
.30
.20
10
0
0
200
400
600
800
1000
2000
TIME (microseconds)

FIGURE 27



LEAKAGE CURRENT IN CERAMIC CAPACITORS
1 0.003 uf 6.2 x 10^12 ohm
2 0.01 uf 8.3 "
3 0.003 uf 11.6 "
4 0.01 uf 11.5 "
1 & 2 RIGHT SCALE
3 & 4 LEFT SCALE
µA
+10
0
-10
-20-2
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
45V
100 K Ω
C

FIGURE 28


LEAKAGE CURRENT IN 60 μf
TANTALUM CAPACITORS, FOIL
1. 1.2 x 10^12 nvt
2. 11.3 "
3. 11.5 "
4. 10.1 "
80 μa
1
2
3
4
μA
30
20
10
0
-10
-20
-30
0
600
800
1000
2000
45V
C0
10 kΩ
SCOPE

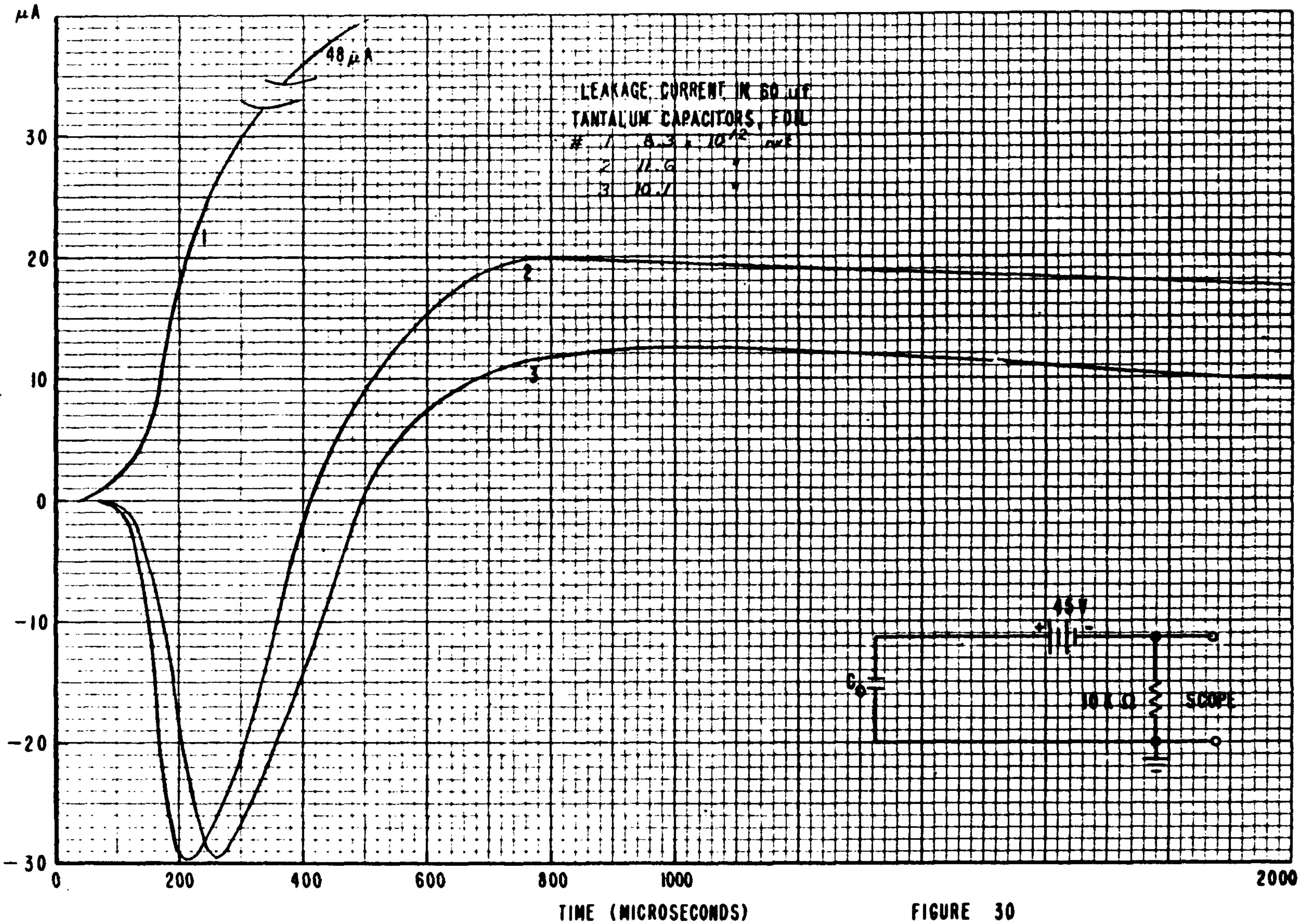
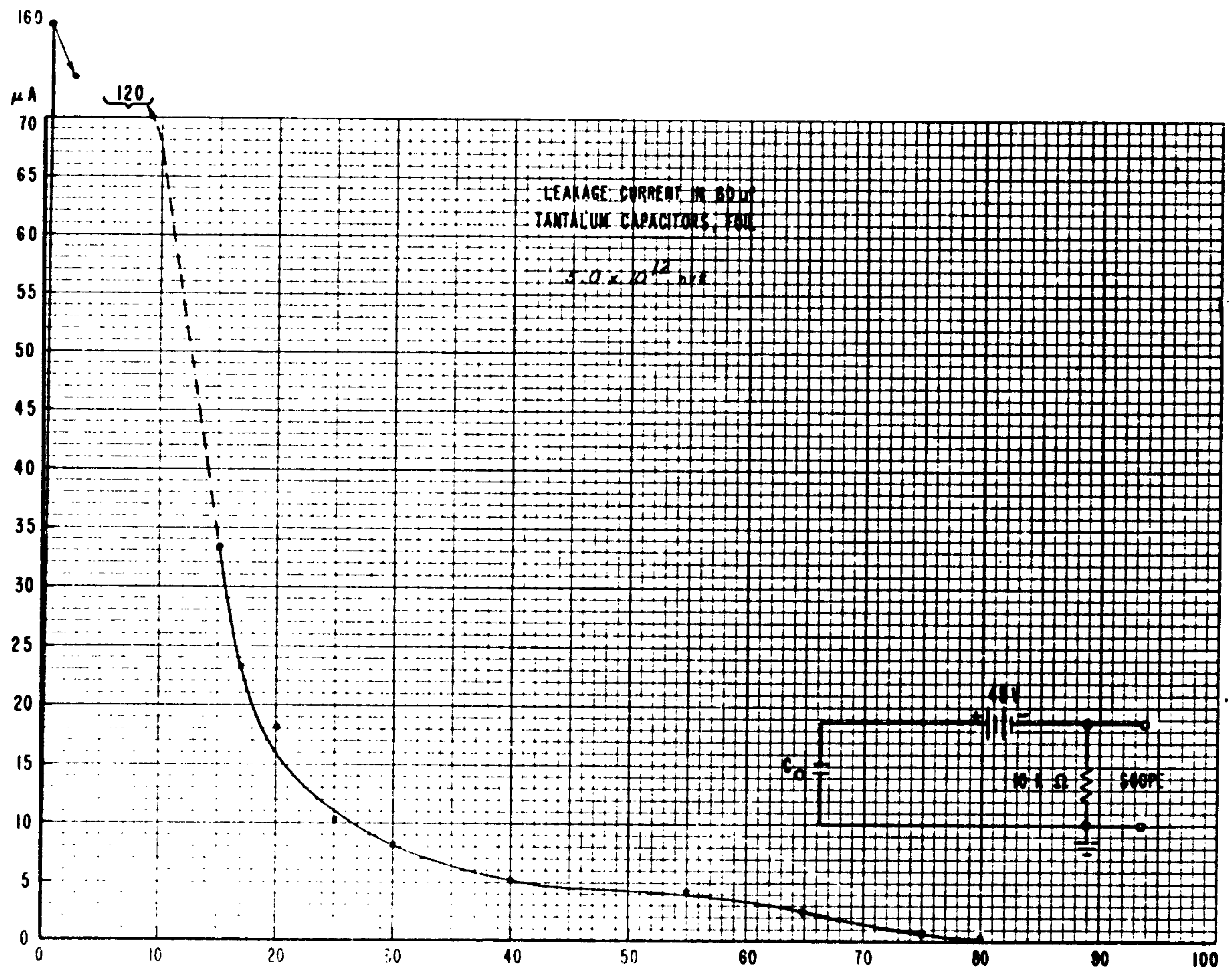

μA
30
20
10
0
-10
-20
-30
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
48 μA
LEAKAGE CURRENT IN 60 μf
TANTALUM CAPACITORS, FOIL
1 8.3 x 10^12 cm²
2 11.6
3 10.1
1
2
3
45 V
+
-
C_p
10 kΩ
SCOPE

FIGURE 30



TIME (MILLISECONDS)

FIGURE 31

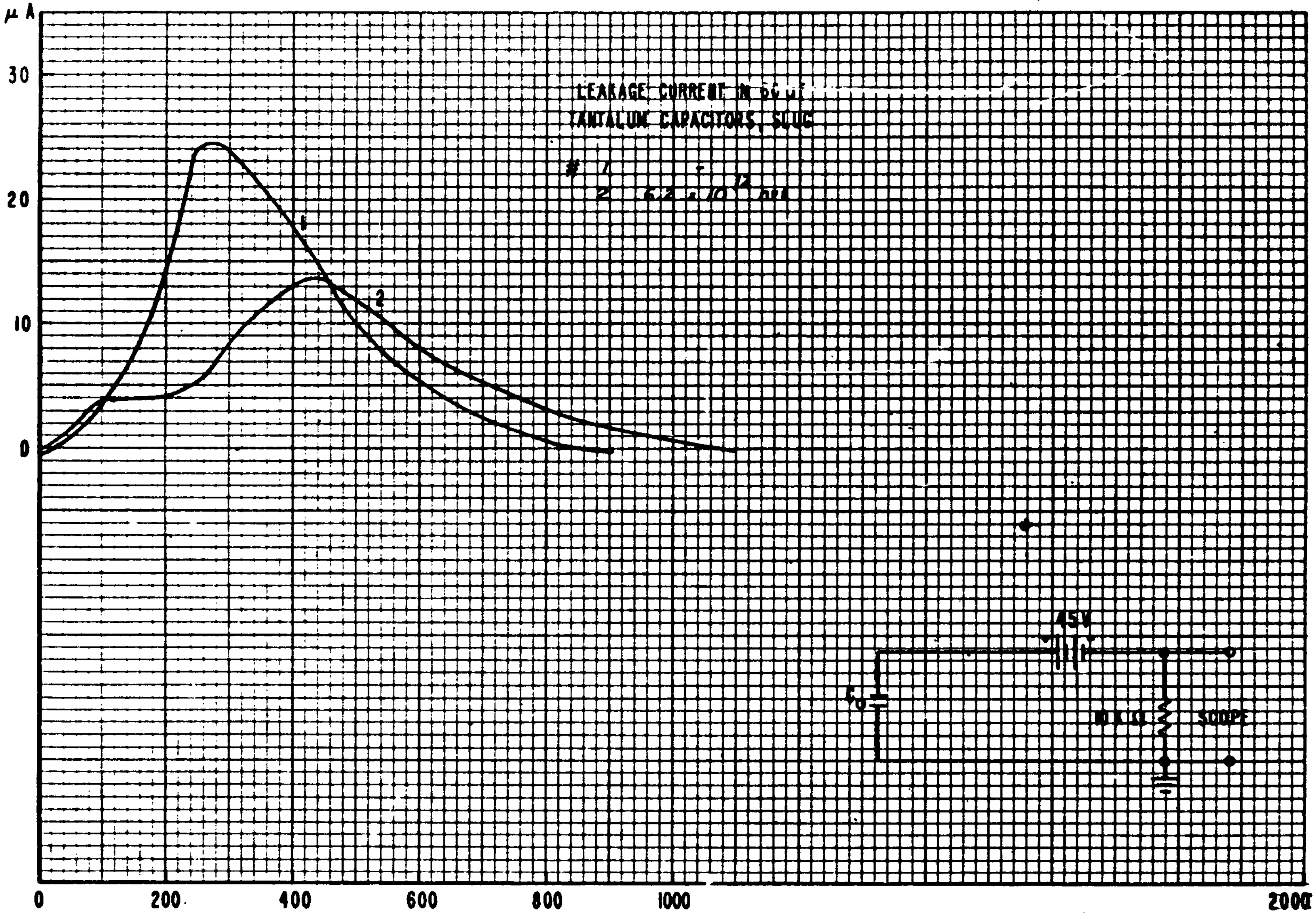
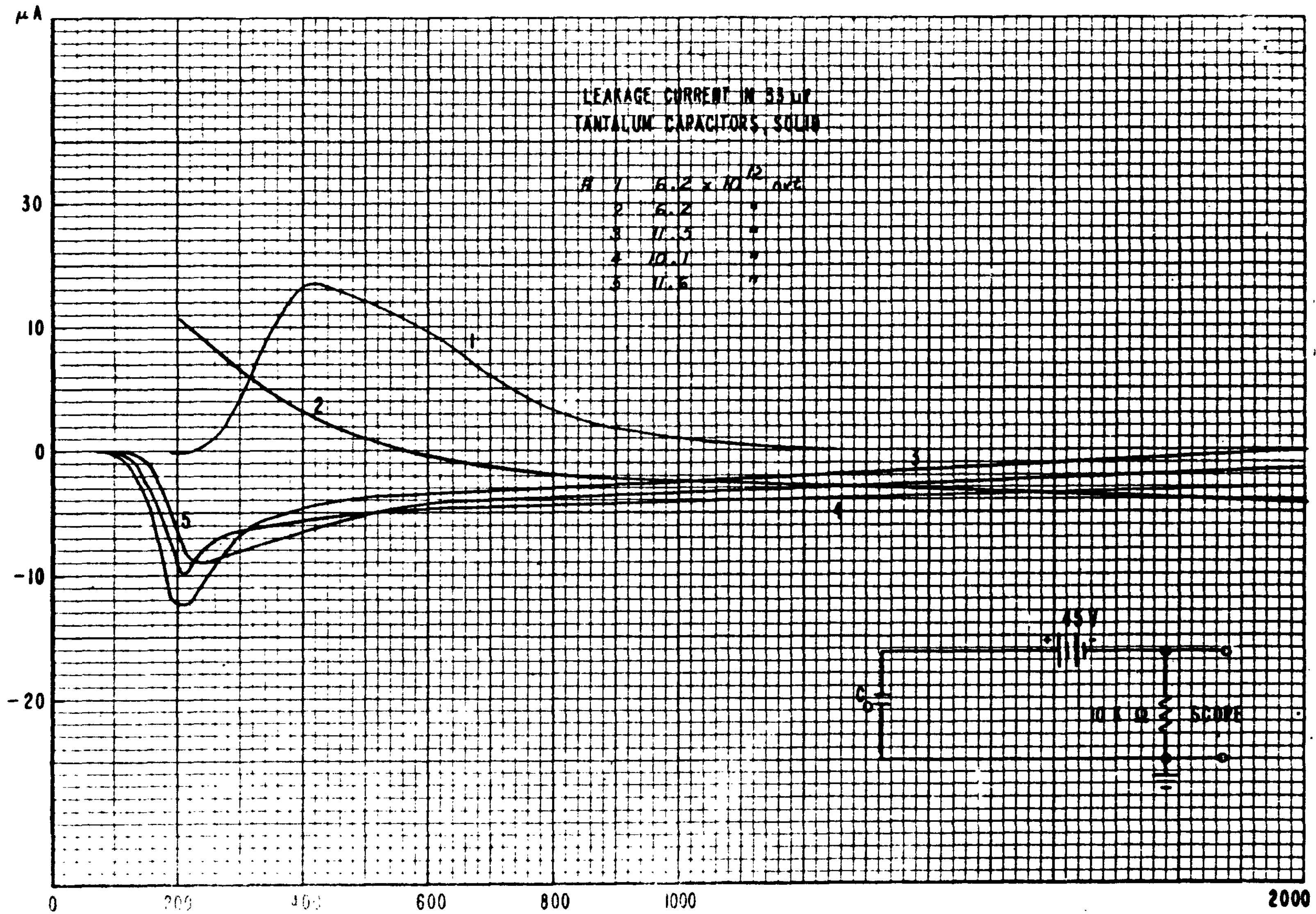

μA
30
20
10
0
0
200
400
600
800
1000
2000
TANTALUM CAPACITORS, SLUG
1
2
45V
SCOPE
TIME (MICROSECONDS)

FIGURE 32


LEAKAGE CURRENT IN 33 µF
TANTALUM CAPACITORS, SOLID
R 1 6.2 x 10^12 nvt
2 6.2 "
3 11.5 "
4 10.1 "
5 11.6 "
µA
30
10
0
-10
-20
0
200
400
600
800
1000
2000
45 V
C_o
10 K Ω
SCOPE

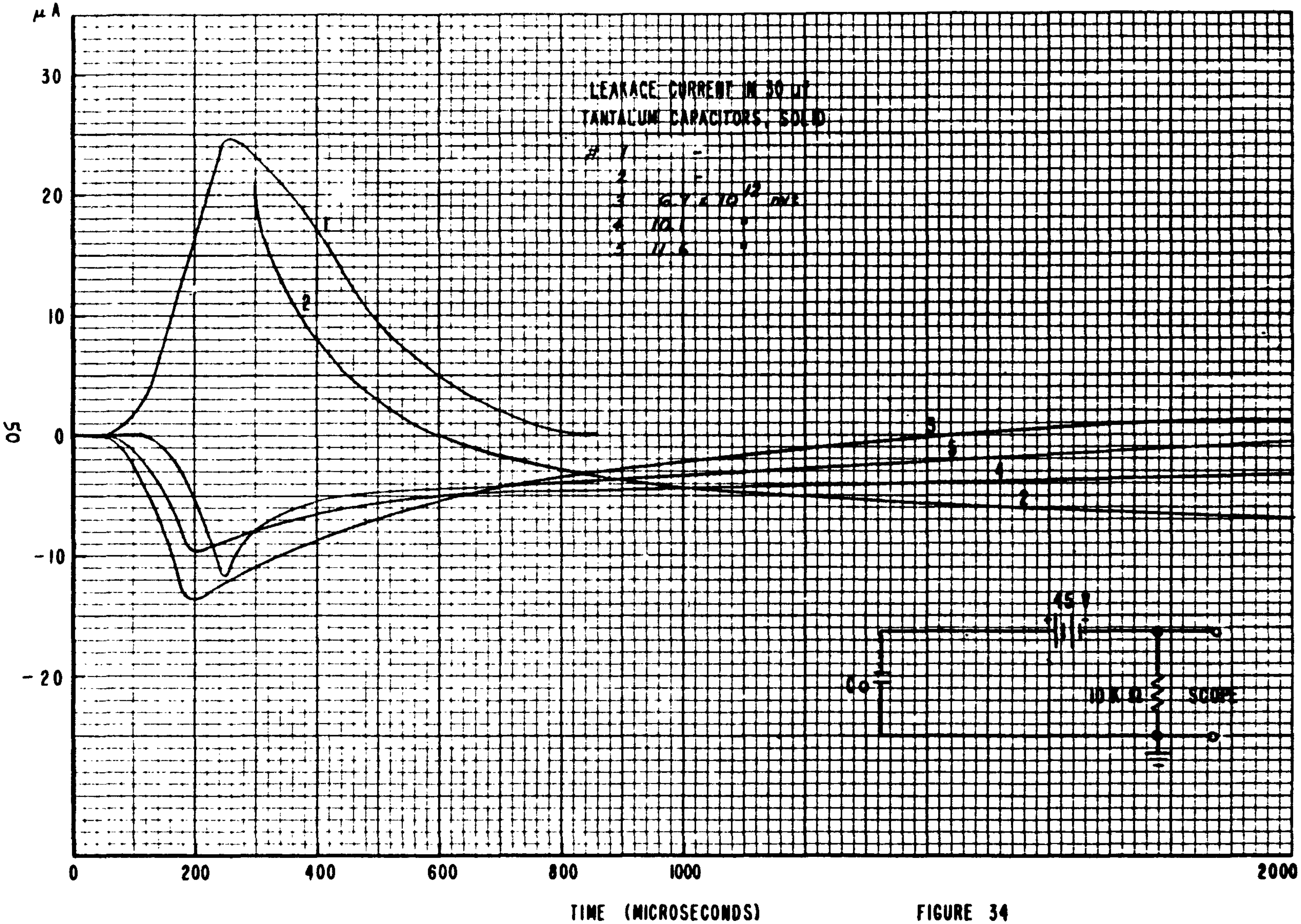

LEAKAGE CURRENT IN 30 µf
TANTALUM CAPACITORS, SOLID
µA
30
20
10
0
-10
-20
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
45 V
10 K Ω
SCOPE

FIGURE 34

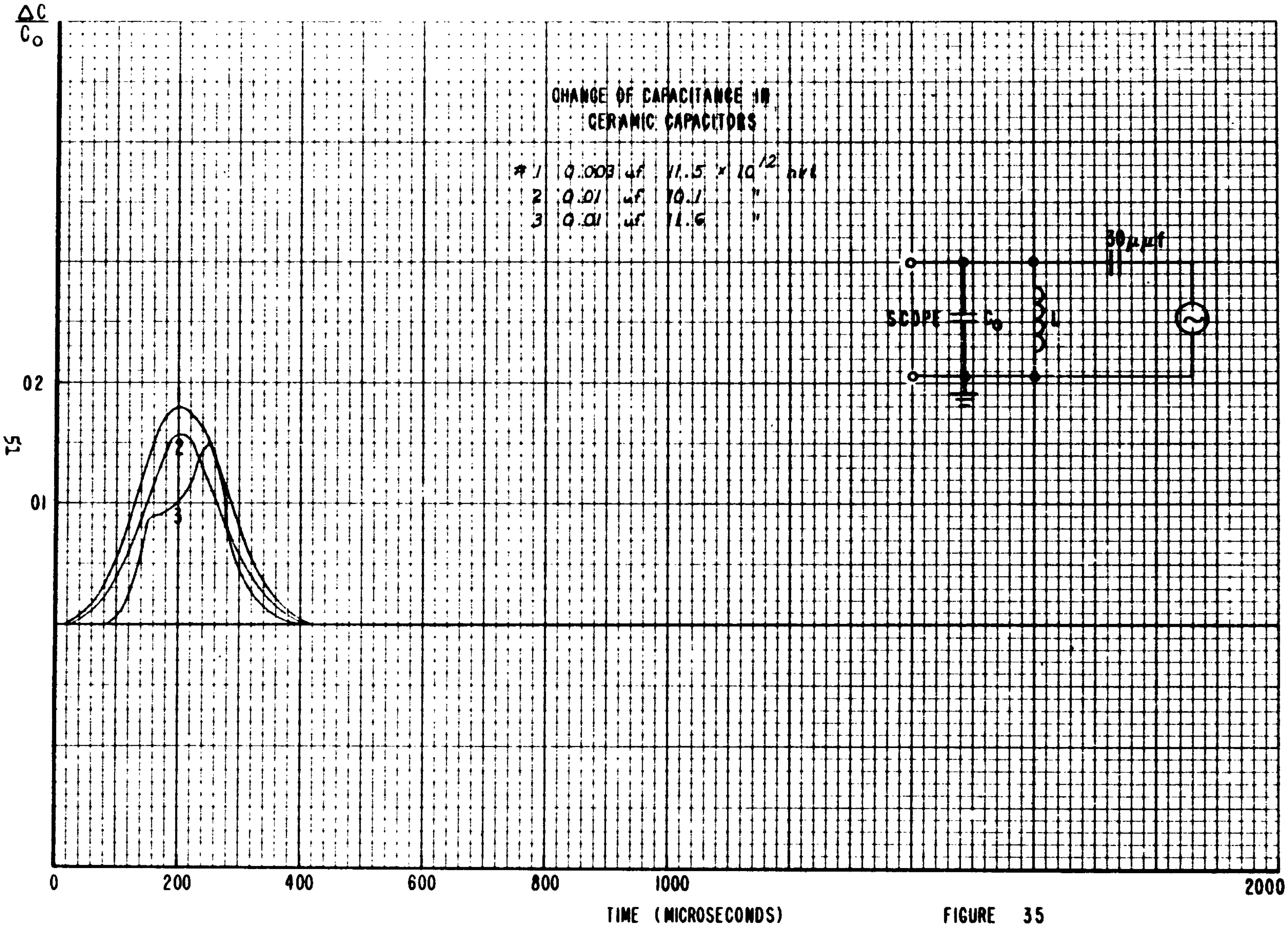

CHANGE OF CAPACITANCE IN
CERAMIC CAPACITORS
1 0.003 uf 11.5 × 10^12 hrs
2 0.01 uf 10.1 "
3 0.01 uf 11.6 "
30μμf
SCOPE
C_0
L
$\frac{\Delta C}{C_0}$
02
01
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 35

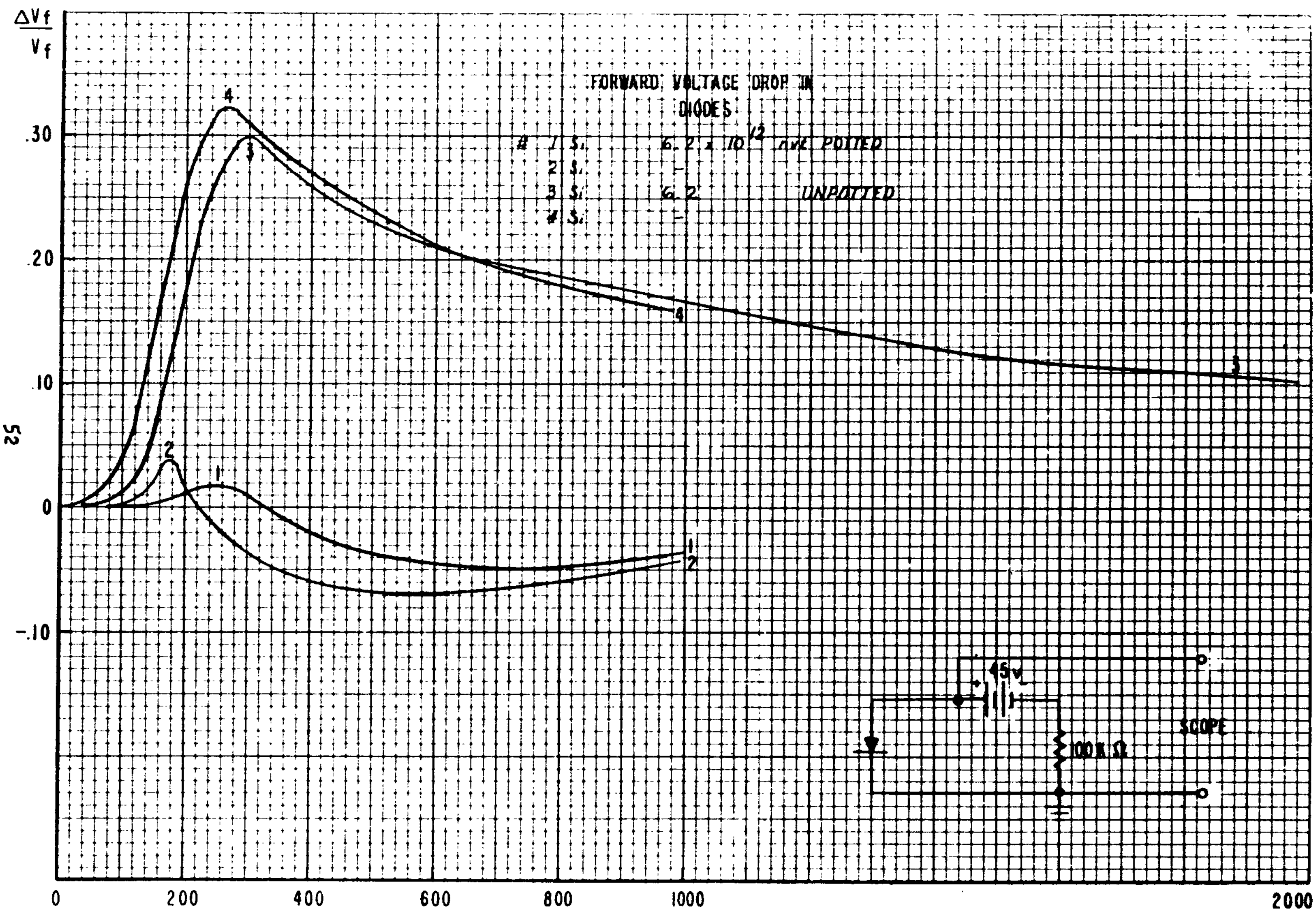

FORWARD VOLTAGE DROP IN
DIODES
1 Si 6.2 x 10^12 nvt POTTED
2 Si –
3 Si 6.2 UNPOTTED
Si –
ΔVf / Vf
.30
.20
.10
0
-.10
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
45v
100 K Ω
SCOPE

FIGURE 36

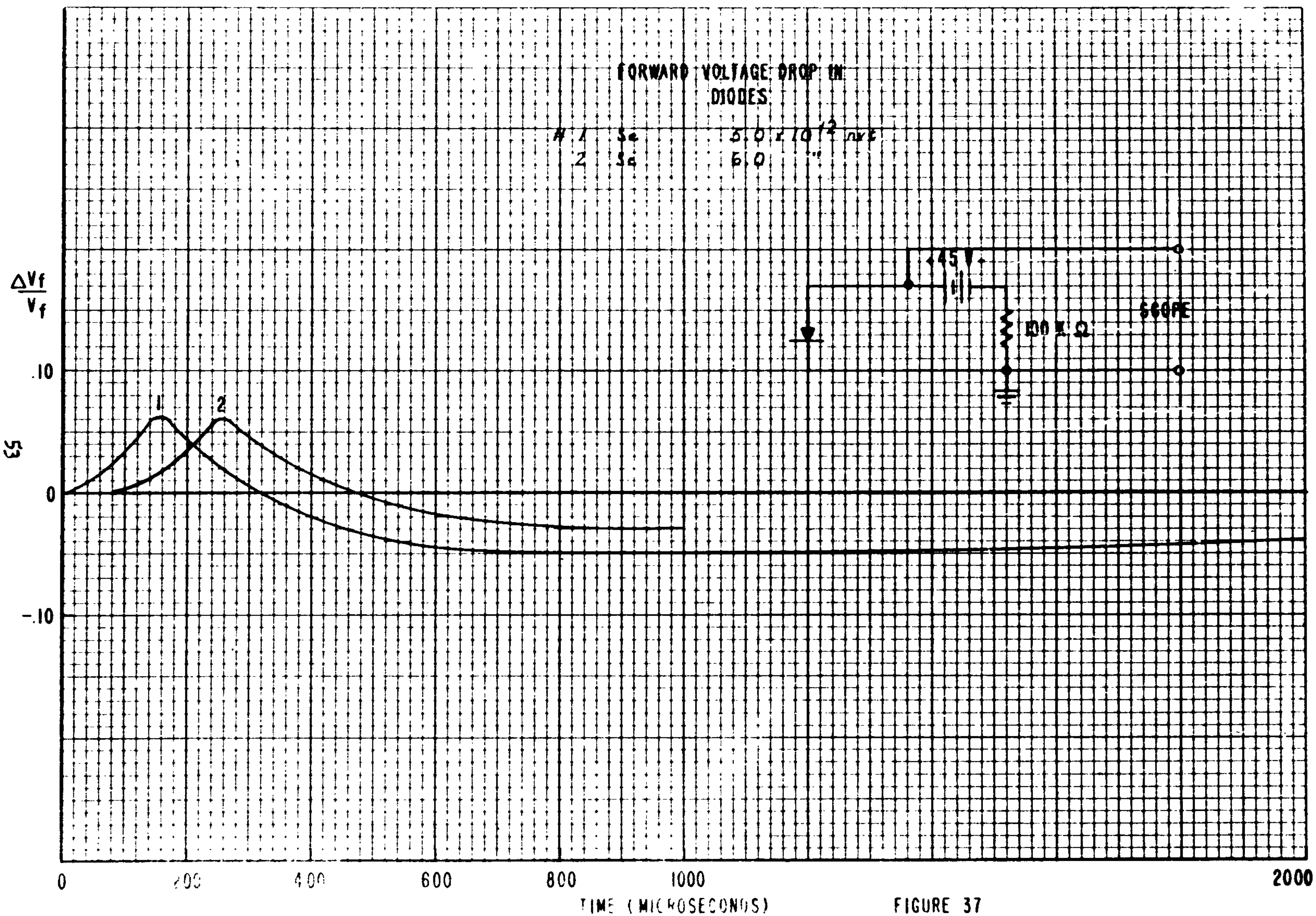

FORWARD VOLTAGE DROP IN DIODES
1 Se 5.0 x 10^12 nvt
2 Se 6.0 "
+45 V -
100 K Ω
SCOPE
1
2
ΔVf/Vf
.10
0
-.10
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 37

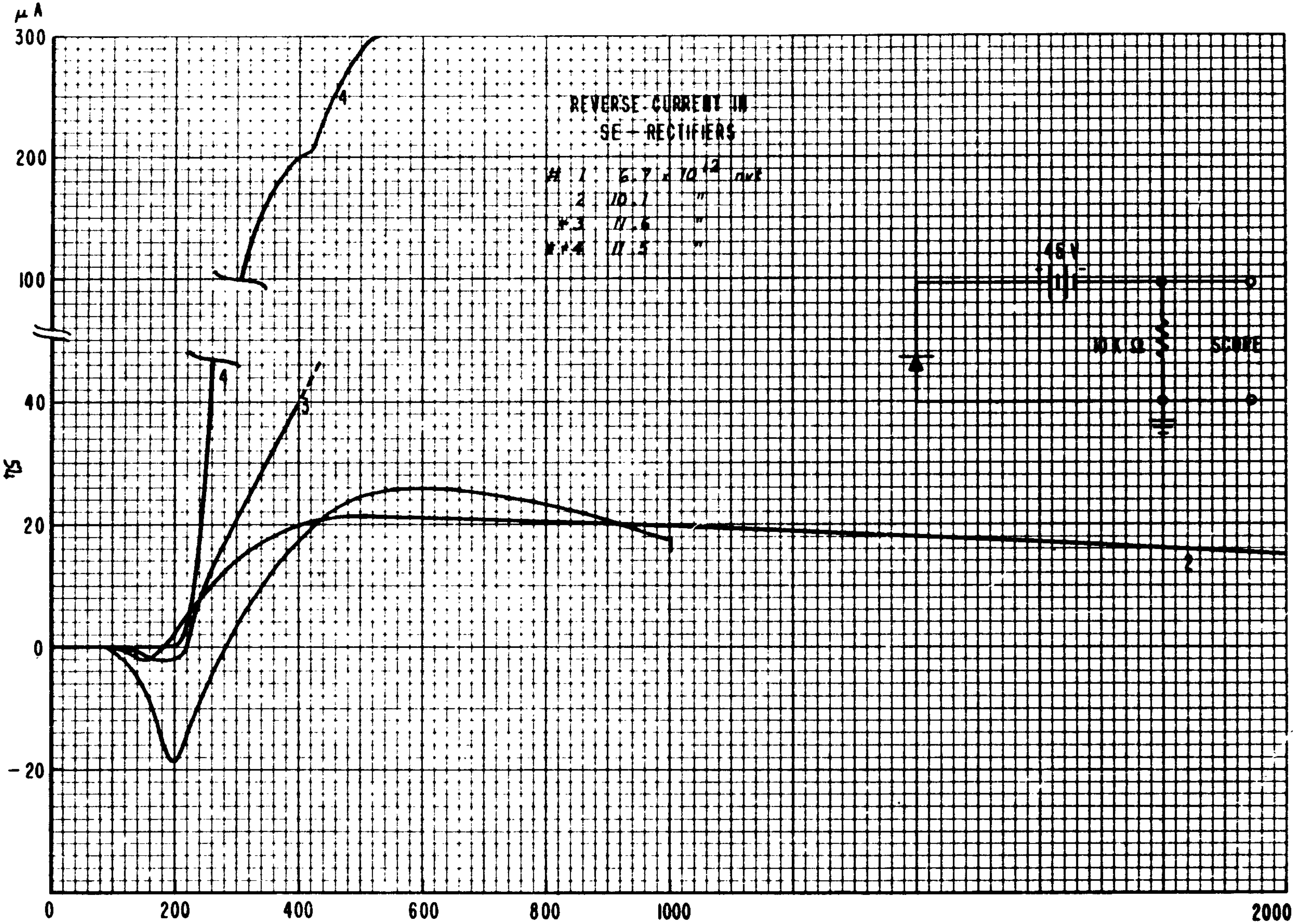
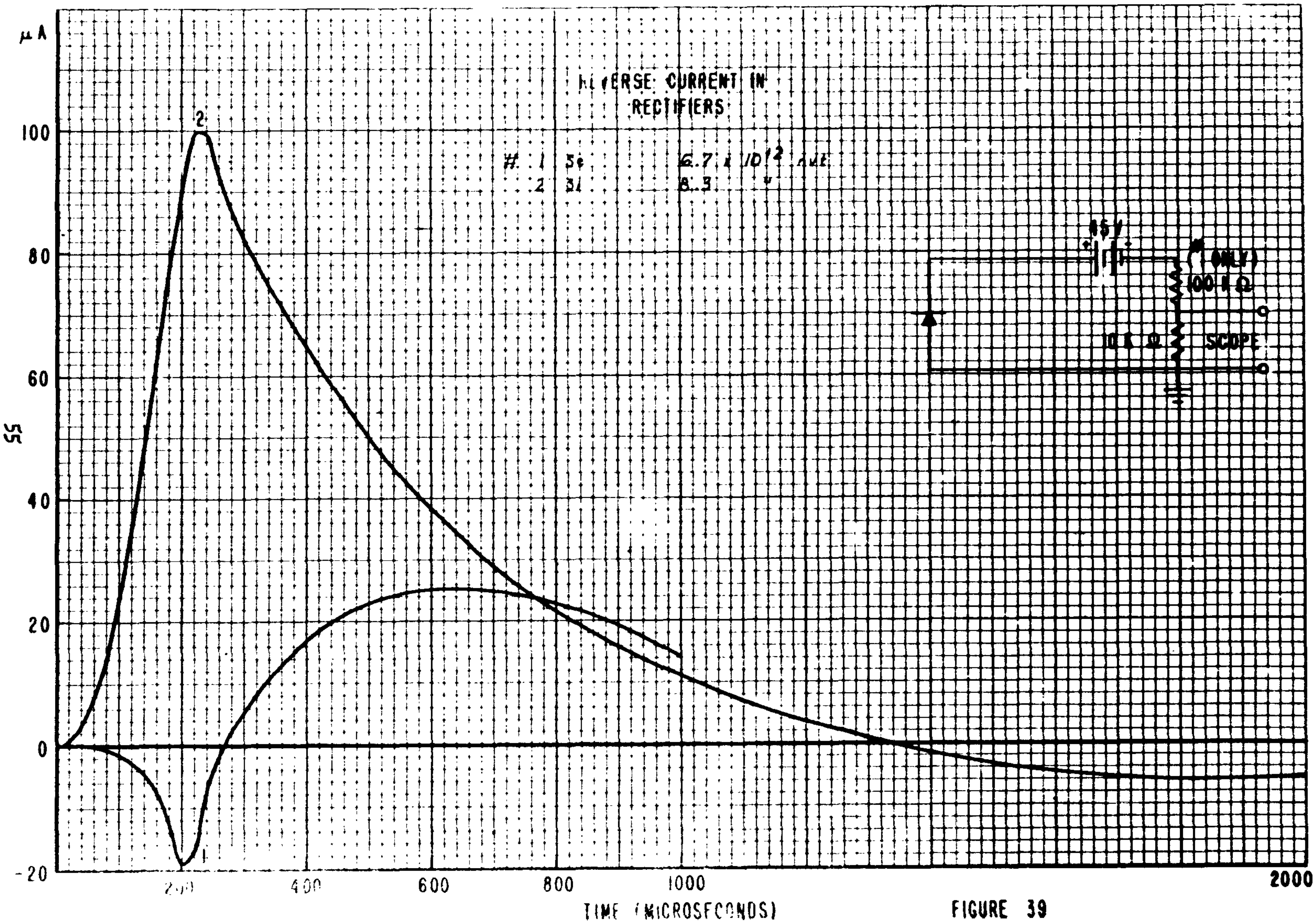
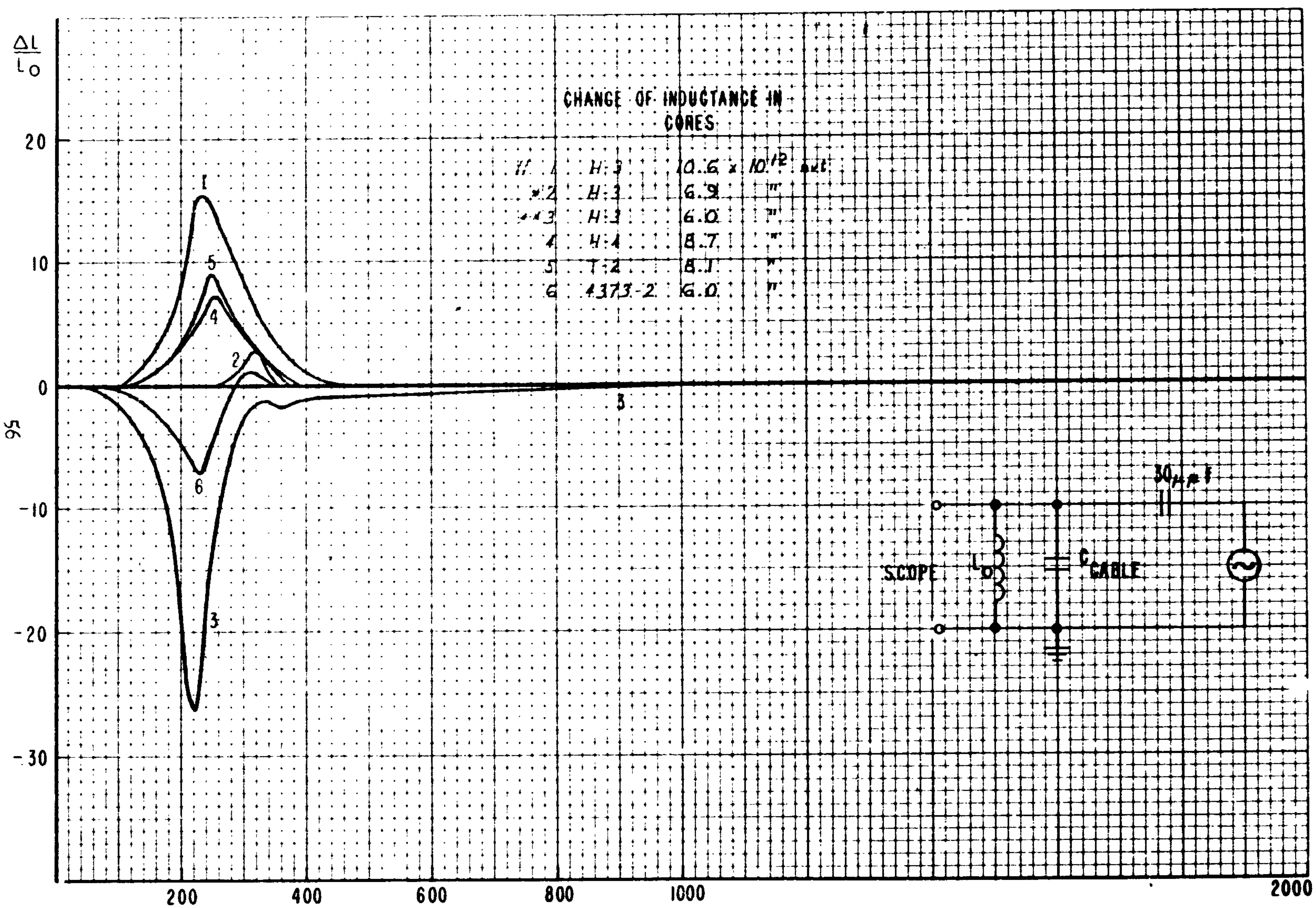

REVERSE CURRENT IN
SE - RECTIFIERS
1 6.7 x 10^12 nvt
2 10.1 "
3 11.6 "
4 11.5 "
45 V
10 K Ω
SCOPE
μA
300
200
100
40
20
0
- 20
0
200
400
600
800
1000
2000
TIME (MICROSECONDS)
1
2
3
4
4

FIGURE 38



REVERSE CURRENT IN RECTIFIERS
1 Se 6.7 x 10^12
2 Si 8.3
45 V
(1 ONLY)
100 K Ω
10 K Ω
SCOPE
μA
100
80
60
40
20
0
-20
200
400
600
800
1000
2000
TIME (MICROSECONDS)

FIGURE 39



$\frac{\Delta L}{L_o}$
20
10
0
-10
-20
-30
200
400
600
800
1000
2000
TIME (MICROSECONDS)
CHANGE OF INDUCTANCE IN CORES
1 H:3 10.6 x 10^12 ...
2 H:3 6.9 "
3 H:3 6.0 "
4 H:4 8.7 "
5 T:2 8.1 "
6 4373-2 6.0 "
SCOPE
L_o
C_{CABLE}
30 μμf

FIGURE 40

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Pulsed nuclear radiation induced changes in the electrical characteristics of electronic parts and materials obtained in two experiments (Godiva IV & V) at the Godiva II Reactor (Los Alamos) are described and discussed. The electronic parts investigated and monitored during exposure include coaxial cables, resistors, capacitors, rectifiers, and magnetic cores of various types, values, and materials. Most of the parts during exposure show transient parameter changes which exceed the tolerance values and then generally recover to their nominal values some time after completion of the radiation pulse. Some of the data show inconsistencies which prevent the authors from drawing definite and quantitative conclusions at the present time. In some cases, e.g., low and high value resistors, NiCr thin-film resistors of various values, and ceramic capacitors, the data show certain repetitive patterns in the behavior of these parts which seem to permit a limited qualitative prediction of the responses of these components under similar environmental conditions. Experiments at Godiva-type (pulsed) facilities are being continued.

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4. Capacitors
5. Rectifiers
6. Magnetic Cores

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5. Rectifiers
6. Magnetic Cores

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